Etude no. 26
Projet 8351-001 Phase 3

# DESIGN OF A LARGE-VOLUME MICROWAVE PLASMA FACILITY

for

METAL PASSIVATION

A final Report

Prepared for the

INDUSTRIAL MATERIALS RESEARCH INSTITUTE
NATIONAL RESEARCH COUNCIL CANADA

by

M.R. Wertheimer

and

H.P. Schreiber

August 16, 1982

CNRC 20612

Note au lecteur:

Les idées exprimées dans ce document sont celles de l'auteur (ou du contractant) et ne sont pas nécessairement partagées par l'Institut de génie des matériaux ou par le Conseil national de recherches Canada. L'auteur (ou le contractant) en assume l'entière responsabilité.

Si la demande est suffisante, des exemplaires supplémentaires de cet ouvrage pourront être disponibles dans la seconde langue officielle (français ou anglais).

Note to the reader:

The views expressed in this document are those of the author (or contractor) who assumes their full responsibility. They are not necessarily shared by the Industrial Materials Research Institute or the National Research Council of Canada.

If sufficient requests are received, a copy of this document will be made available in the other official language (French or English).

## SUMMARY

Laboratory-scale technical feasibility studies have shown that large-volume microwave plasma (LMP) processes can produce sophisticated surface coatings on metal, polymer, ceramic and other substrates. Full-scale industrial utilization requires the construction of a development and demonstration unit to develop coating and process specifications at the industrial scale. The objective of this project was to design an LMP facility capable of continuous operation to permit credible demonstration of the LMP process for a wide range of industrial applications and to generate the necessary data base on which to tailor, construct and operate industrial-scale units.

A flexible development and demonstration system was designed for the following types of applications of the LMP process: metal passivation, encapsulation, moisture barrier coatings, treatment of fibers and fillers for use in high-performance composites, and dielectric, optical, and tribological coatings. The project examined a series of design options for a large-volume microwave plasma facility for metal passivation. It presented the engineering options in both technical and economic contexts. Non-technical considerations included cost and the range of applications (market) as well as the role the unit is to play in penetrating the market. Market considerations identified five types of substrate geometries: filamentary materials such as metallic wires and polymeric fibers, flat disks ranging from small lenses to 18" diameter disks and square and rectangular plates, particulates, discrete parts such as screws, washers, and nuts, and rod and tubular parts.

System options considered included a dedicated unit designed to optimize substrate transport for wire coating. An agreement was reached with Canwirco Ltd to obtain industrially relevant parameters upon which to base a design. Dedicated to continuous substrates, this unit was designed using four plasma reactors in series. After cleaning, the substrate is heated and cycled through the plasma several times in each reactor. Using a staged vacuum, substrate feed and wind-up occur at atmospheric pressure. Each of the four reactors has independent monomer feed and substrate temperature controls. The process is completed by thermal conditioning of the plasma-coated substrate in an in-line oven.

The treatment of discrete substrates (e.g. lenses, disks, turbine blades, fasteners, etc.) clearly involves a batch operation. In the two other design options the substrate feed and wind-up equipment is all housed within the same vacuum chamber. Elimination of the vacuum lock of the dedicated unit greatly simplifies the operation of a pilot unit and reduces its cost. Most importantly, it provides the desired flexibility of

application lacking in the dedicated unit since continuous air-to-air operation could only be designed for substrates of closely specified geometry. Significant deviations from that geometry would require appreciable changes in pumping capacity, the shape and size of entry and exit ports, etc. Both technical and economic (market) considerations suggested that the wire coating application was not the best target upon which to base the construction of a development and demonstration unit. The discrete parts markets are more diverse and simpler to handle. Thus the risk involved in the investment in the system would be minimized by spreading it over a wider range of potentially technically feasible projects.

The second design option was a single flexible unit into which was integrated the capability of handling a wide range of substrate geometries. This unit was based on a commercial vacuum system with a cylindrical vacuum chamber of the type used for other vacuum coating applications. Thus, the basic vacuum, substrate transport and reactant gas feed subsystems would be off-the-shelf equipment to which would be added approximately eight microwave windows and proprietary LMP coating applicator assemblies. The basic vacuum chamber houses a substrate "rack", which in presently available form accepts discrete substrates of various geometries. A second rack comprising streaming transport mechanisms would accommodate continuous substrates, including multi-strands of wire in a range of diameters, as well as other forms of continuous substrates, e.g. web, filament, tape, etc. However, eight such transport mechanisms would present an extremely complex mechanical system.

The third design option was a completely modular system. It is based on two transport modules between which is placed the applicator module. Auto-entry and exit modules could be added later. Both the transport and applicator modules would integrate maximum commonality vis-a-vis a wide range of applications. This design would be inherently simpler than the flexible cylindrical system above. It would comprise modules with rectangular crossections and could be operated either vertically or horizontally. The transport modules would have a common drive for a conveyor of discrete parts (with vibration for small parts and particulates), for pulleys or grooved drive rolls for wires and filaments, and for advancing long rods and tubes through the applicator. It could likewise drive a drum inside the applicator should this be more appropriate for particulates. In this system, substrate positioning within the window is simpler and substrate-to-applicator distance is maitained constant. Extention to multi-applicator stages and to continuous entry and removal is simple. Transport mechanisms in the rectangular system can be made simpler for 100% vertical transport, the preferred orientation for quality coating. A major disadvantage to this approach may be cost. The rectangular chambers are inherently more expensive to build than the cylindrical chambers. However, since the unit is modular, it can be fabricated on a modular basis and a single application could be addressed initially at a

cost competitive with the other options. A budgetary estimate of the order of $500,000 is in order for the latter modular development and demonstration unit and the total time to operations is estimated to be 46 weeks.

Thus the cylindrical geometry is indicated for lowest entry-level cost for a limited number of applications exclusive of wire, filament, strip and web substrates. A series of units designed specifically for and dedicated to single applications would not be cost effective for general development and demonstration purposes. The rectangular modular configuration is recommended when the number of applications is likely to be large and the range of applications is likely to include filamentary tape and web substrates. The latter is also superior with respect to technical features such as flexibility, simplicity of mechanisms, and substrate orientation. All are optimized in the rectangular configuration. It provides the opportunity for the greatest simplicity and maximum flexibility and adaptability from the technical point of view at an overall cost penalty which can be minimized by acquiring the system on a modular basis.

Résumé:

Des études de faisabilité technique à l'échelle du laboratoire ont montré qu'il est possible d'obtenir des revêtements complexes sur des surfaces métalliques, des matières plastiques, des céramiques ou d'autres substrats par des procédés avec plasmas micro-ondes. L'utilisation des procédés à l'échelle industrielle suppose d'abord la construction d'une machine de développement et de démonstration permettant d'établir les spécifications industrielles des revêtements et des procédés. L'objectif du projet était de concevoir une machine à plasma micro-ondes pouvant fonctionner en continu, afin de prouver l'applicabilité des procédés à une grande gamme d'opérations industrielles et de rassembler les données nécessaires à la conception, à la construction et à l'exploitation de machines industrielles spécialisées.

Un système souple de développement et de démonstration a été conçu pour les applications suivantes: passivation des métaux, encapsulation, revêtements pour barrière contre l'humidité, traitement des fibres et des matières de charge utilisées dans des composites de haute performance et revêtements diélectriques, optiques et tribologiques. Dans le cadre du projet, on a examiné plusieurs conceptions possibles d'une machine destinée à la passivation des métaux. Les conceptions ont été étudiées des points de vue technique et économique. Parmi les aspects non techniques, on a considéré le coût, la gamme d'applications (marché) et le rôle de la machine dans la pénétration du marché. En ce qui concerne les débouchés, on a retenu cinq types de géométrie du substrat: les filaments tels que fils métalliques et fibres de plastique, les disques plats allant des petites lentilles à

des disques de 18 po de diamètre, les plaques carrées et rectangulaires, les particules, les pièces telles que vis, rondelles et écrous, ainsi que les tiges et pièces tubulaires.

Les différentes options envisagées incluaient une machine spécialisée conçue de façon à optimiser le transport du substrat dans le cas du revêtement de fils. La société Canwirco a accepté de fournir les paramètres industriels pertinents devant servir de base à la conception. La machine, destinée à des substrats continus, compte quatre réacteurs à plasma placés en série. Après nettoyage, le substrat est chauffé et passé dans le plasma plusieurs fois dans chaque réacteur. L'utilisation d'un pompage différentiel permet de faire l'alimentation et l'enroulement du substrat à la pression atmosphérique. Chaque réacteur est équipé de ses propres systèmes d'alimentation en monomère et de réglage de la température du substrat. Le traitement se termine par un conditionnement thermique du substrat revêtu dans un four placé en série.

Il est clair que les petites pièces (lentilles, disques, aubes, attaches, etc.) ne peuvent être traitées que par lots. Les deux autres machines envisagées sont conçues de telle sorte que les systèmes d'alimentation et d'enroulement du substrat soient placés dans la même chambre à vide. L'élimination du sas continu du dispositif spécialisé simplifie beaucoup les opérations et réduit les coûts. Surtout, cette nouvelle conception permet une souplesse d'application que la première machine n'a pas, les opérations air-air ne pouvant s'appliquer

qu'à des substrats de géométrie bien définie. De trop grands écarts dans la géométrie impliqueraient des changements notables dans la capacité de pompage, dans la forme et la taille des ouvertures d'entrée et de sortie, etc. Les considérations techniques et économiques (marché) ont montré que le revêtement de fils n'est pas la meilleure application à envisager comme base de construction d'une machine de développement et de démonstration. Les marchés des pièces sont plus diversifiés et plus simples. Le risque serait ainsi atténué par dilution sur une plus grande gamme de projets techniquement viables.

La deuxième solution consiste en une machine unique et souple acceptant des substrats de géométrie très variée. Cette machine est basée sur un système commercial doté d'une chambre à vide cylindrique de même type que celle utilisée pour d'autres opérations de revêtement sous vide. Les composantes de base pour le vide, le transport du substrat et l'alimentation en gaz réactif sont donc des appareils déjà fabriqués industriellement auxquels viennent s'ajouter environ huit fenêtres à micro-ondes et les applicateurs à plasma brevetés. La chambre à vide de base contient un support à substrat qui, sous la forme actuellement disponible, accepte de petites pièces de géométries diverses. Un deuxième support comprenant des mécanismes de déroulement accepterait des substrats continus comme des fils multi-brins de divers diamètres, des feuilles, des filaments, des rubans, etc. Cependant, huit mécanismes de déroulement de ce type constitueraient un système mécanique extrêmement complexe.

La troisième machine étudiée est d'une conception complètement modulaire. Elle comprend deux modules de transport entre lesquels est placé le module de dépôt. Des modules d'entrée et de sortie automatiques peuvent être ajoutés par la suite. Les modules de transport et de dépôt sont choisis de façon à permettre la plus grande gamme possible d'applications. Une telle machine est intrinsèquement plus simple que le système cylindrique souple mentionné ci-dessus. Les modules ont des sections rectangulaires et ils peuvent fonctionner horizontalement ou verticalement. Les modules de transport ont un système d'entrainement commun soit pour un transporteur de pièces (avec des vibrations pour les petites pièces et les particules), soit pour des poulies ou des rouleaux à rainures pour les fils et les filaments, soit encore pour faire avancer les longues tiges et les tubes à travers le module de dépôt. Le système d'entrainement peut aussi actionner un tambour à l'intérieur du module de dépôt si ceia convient mieux pour les particules. Dans ce système, la mise en place du substrat devant la fenêtre est plus simple et la distance entre le substrat et l'applicateur est maintenue constante. On peut facilement modifier la machine pour qu'elle accepte plusieurs applicateurs et ajouter un mécanisme d'entrée et de sortie continues. Il est possible de simplifier les mécanismes de transport dans le système rectangulaire pour que le transport se fasse à 100% verticalement, la position verticale assurant une qualité de revêtement optimale. Le principal inconvénient est peut-être le coût. La construction des chambres rectangulaires est plus coûteuse que celle des chambres cylindriques. Cependant, la machine étant modulaire, on peut envisager au départ une seule application et fabriquer les

modules à un coût comparable à celui des autres machines étudiées. On peut s'attendre à un investissement de l'ordre de $500,000 pour la machine modulaire et le temps total avant le début des opérations est évalué à 46 semaines.

En conclusion, le modèle cylindrique convient si l'on veut réduire au minimum les frais d'investissement. Ses applications sont limitées et elles excluent les fils, les filaments, les bandes et les feuilles. Une série d'unités conçues spécialement pour des applications particulières ne serait pas rentable dans le cadre d'un projet de développement et de démonstration. La machine modulaire rectangulaire est recommandée lorsqu'on prévoit un grand nombre d'applications, avec des substrats sous forme de filaments, de rubans et de feuilles. Du point de vue technique, la configuration rectangulaire offre un maximum de simplicité, de souplesse et d'adaptabilité. Du point de vue économique, l'acquisition du système module par module permet de réduire au minimum l'inconvénient du coût.

# TABLE OF CONTENTS


| | | Page |
|---|---|---|
| 1. | INTRODUCTION - SYSTEM CAPABILITY SPECIFICATIONS | 1 |
| 1.1 | THE LARGE-VOLUME MICROWAVE PLASMA PROCESS | 1 |
| 1.2 | PROJECT OBJECTIVES | 1 |
| 1.3 | PRODUCT RANGE | 2 |
| 1.4 | SUBSTRATE GEOMETRY RANGE | 3 |
| 1.5 | SCALE - CAPACITY | 3 |
| 2. | TECHNICAL DESCRIPTION - DESIGN SPECIFICATIONS | 4 |
| 2.1 | GENERAL DESIGN CONSIDERATIONS | 4 |
| 2.1.1 | General LMP System Features | 4 |
| 2.1.2 | General Systems Options | 6 |
| 2.2 | THE DEDICATED UNIT | 14 |
| 2.2.1 | Selection of the Application | 14 |
| 2.2.2 | Design Criteria | 14 |
| 2.2.3 | Conceptual Design | 15 |
| 2.2.4 | Schematic Design | 15 |
| 2.2.5 | Detailed Design | 18 |
| 2.2.6 | Evaluation | 32 |
| 2.3 | THE ADAPTIVE DESIGN | 34 |
| 2.3.1 | Conceptual Design | 34 |
| 2.3.2 | Schematic Design | 35 |
| 2.3.3 | Detailed Design | 36 |
| 2.3.4 | Cost Analysis | 37 |
| 2.3.5 | Construction Schedule | 38 |
| 2.3.6 | Evaluation | 38 |

# TABLE OF CONTENTS


| | Page |
|---|---|
| **3. TECHNICAL DISCUSSION** | **39** |
| 3.1 TECHNICAL COMPROMISES | 39 |
| 3.2 ECONOMIC COMPROMISES | 39 |
| **4. CONCLUSIONS AND RECOMMENDATIONS** | **41** |
| APPENDIX A: CVE Study proposal and experimental results | 42 |
| APPENDIX B: LH and HVS standard equipments; modifications of LH unit | 49 |
| APPENDIX C: Lists of suppliers of major components | 76 |
| APPENDIX D: Pilot plant specifications, technical responses and quotations | 102 |


* * * * * * * * *

# LIST OF FIGURES


| Figure | Title | Page |
|---|---|---|
| 1 | The applicator assembly ..... | 5 |
| 2 | Comparison of laboratory and industrial units ..... | 5 |
| 3 | Dedicated system ..... | 8 |
| 4 | The single flexible system ..... | 9 |
| 5 | Sample substrate holder configurations ..... | 10 |
| 6 | The completely modular system ..... | 12 |
| 7 | Modular system orientations ..... | 13 |
| 8 | Dedicated wire coating system ..... | 16 |
| 9 | Schematic diagram of subsystem ..... | 19 |
| 10 | Plasma length vs tichness/deposition rate ratio ..... | 22 |
| 11 | Plasma length vs tickness/deposition rate ratio ..... | 23 |
| 12 | Plasma length vs wire streaming velocity ..... | 24 |
| 13 | Schematic system used for pressures determination .... | 25 |

# 1. INTRODUCTION - SYSTEM CAPABILITY SPECIFICATIONS

## 1.1 THE LARGE-VOLUME MICROWAVE PLASMA PROCESS

Numerous laboratory-scale technical feasibility studies carried out at Ecole Polytechnique de Montreal have shown that large-volume microwave plasma (LMP) processes could enjoy many applications in the production of sophisticated surface coatings and of surface modifications to metal, polymer, ceramic and other substrates. Further progress from laboratory experiments to full-scale industrial utilization requires the construction of a development and demonstration unit to develop coating and process specifications at the industrial scale. Construction of such a unit was recommended in a report on a techno-economic feasibility study carried out by F.T. Gerson Ltd. on behalf of the Industrial Materials Research Institute (IMRI). Accordingly, the present study was undertaken for IMRI.

## 1.2 PROJECT OBJECTIVES

The major objective of this project was to:

DESIGN AN LMP FACILITY CAPABLE OF CONTINUOUS OPERATION

This facility was to be designed subject to several general criteria, namely:

* it should serve the broad market area of wire coating,

* it should incorporate sufficient flexibility to allow for the treatment of tape, strip and similar geometries.

* it should be a first module to be expanded on or included in future development and demonstration apparatus to be brought into operation as demanded by the number and scale of applications for LMP technology.

* capital expenditure was to be minimized while assuring that the scale of the facility was sufficiently large to carry out realistic development and demonstration projects for potential industrial users.

## 1.3 PRODUCT RANGE

Current expressions of interest from industrial firms provide an insight into the range of products to which considerable value can be added by applying LMP coatings or surface modifications. The list of applications presented below comprises only those where the LMP is uniquely suited and where it does not compete with existing processes because it is recognized that the latter are not capable of meeting the exacting demands of the application.

Among the types of applications for the LMP process are the following:

* metal passivation
* encapsulation
* moisture barriers
* treatment of fibers and fillers for use in high-performance composites
* dielectrics
* optical
* **tribological**

**DEVELOPMENT UNIT APPLICATIONS**

| Geometry | Potential Client(s) | |
|---|---|---|
| wire | Enamelled wire producer and equipment manufacturer | * |
| fibers | Primary polypropylene producer, fiber and fabric producers (polypropylene) | * |
| | U.S. military agency (carbon fibers) | |
| | Plastics supplier | * |
| web | Polyester-cotton fabric producer | * |
| | polypropylene film for solar heat conservation device (manufacturer) | * |
| | metallic foil for capacitor fabrication | |
| particulates | metal - polymer composites (manufacturer) | |
| | mica flakes - polymer composites manufacturer | * |
| discrete parts | optical disks (two manufacturers) | |
| | turbine blade manufacturer | * |
| | metal surfaces - two ore processing plants | * |

* Canadian application

There is therefore a widely diverse range of potential products to which the LMP process is applicable in both the domestic and foreign market places. Accommodating the future requirements of a large fraction of these potential applications imposes a need for a high level of flexibility in the development and demonstration unit.

## 1.4 SUBSTRATE GEOMETRY RANGE

The list of applications in the previous section represent a wide range of substrate geometries. They can be grouped into five categories which include:

1. Filamentary materials such as metallic wires and polymeric fibers.
2. Flat disks ranging from small lenses to 18" diameter disks and square and rectangular plates.
3. Particulates.
4. Discrete parts such as screws, washers, and nuts.
5. Rod and tubular parts.

## 1.5 SCALE - CAPACITY

The system should be able to coat substrates in the geometries listed in the previous section whose dimensions approach those of the scale required by potential users for evaluation of coatings and surface layers under conditions closely approaching or identical to the actual substrate configuration used in practice to facilitate characterization and evaluation with respect to end use. Development and demonstration at this scale is required to avoid the need for additional major development work prior to industrial application.

Factors involved in scaling include speed of substrate transport and the size and quantity of substrate to be treated.

# 2. TECHNICAL DESCRIPTION - DESIGN SPECIFICATIONS

## 2.1 GENERAL DESIGN CONSIDERATIONS

### 2.1.1 General LMP System Features

An LMP system designed for coating or modifying substrate surfaces comprises four subsystems:

* the vacuum subsystem
* the microwave subsystem
* the reactant gas feed subsystem
* the substrate transport subsystem

These subsystems are integrated into a system which the substrate enters, is treated and is removed. The microwave subsystem remains outside the vacuum. The four systems interact at the microwave window, a key element in an industrial system, as shown in Figure 1. Here, the slow wave structure, the unique patented device which makes the LMP process possible, is placed in front of the window outside the vacuum. The microwave field created by the structure traverses the window and creates a plasma in the reactant gas which is maintained at an appropriately low pressure by the vacuum system. Existing laboratory and envisaged industrial systems differ in their respective window/plasma configurations. Laboratory units are usually small cylindrical glass containers which are completely filled with the plasma in the vicinity of the slow wave structure. In the larger volume industrial systems, there will be one or more windows, each of which will support its own localized plasma. These two cases are compared schematically in Figure 2. One of the major considerations in designing the industrial unit was to determine the optimal window and substrate transport subsystem configuration which would provide the most flexibility and adaptability.

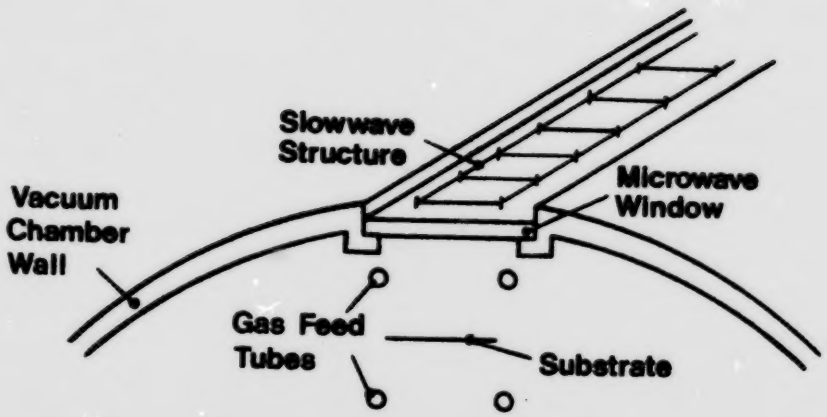



FIGURE 1. APPLICATOR ASSEMBLY

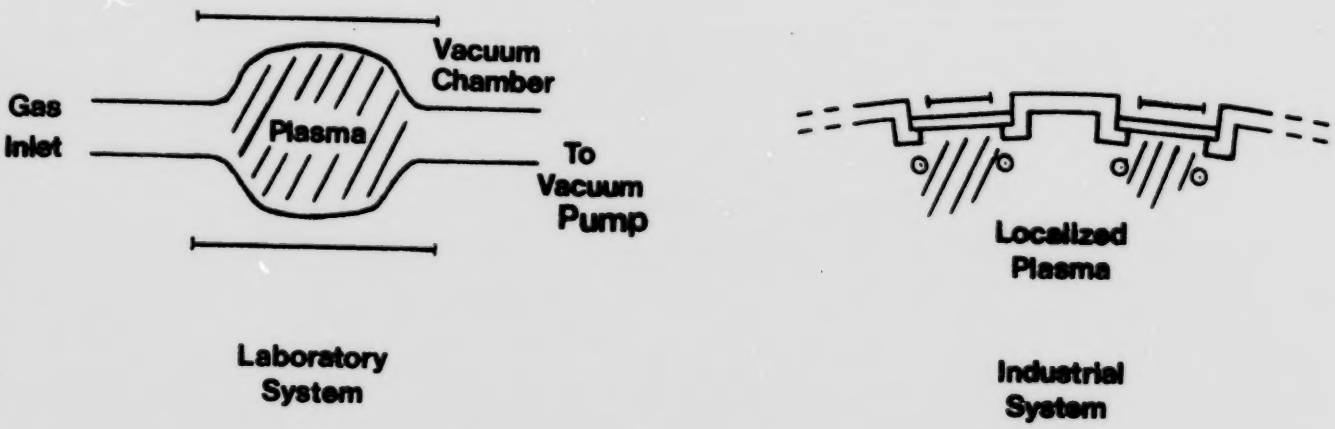



FIGURE 2. COMPARISON OF PROPOSED INDUSTRIAL DEVELOPMENT UNIT WITH EXISTING LABORATORY UNIT

The requirement that the system be continuous requires some definition in the context of vacuum systems. A continuous process differs from a batch process by presenting a continuous flow of substrate to the active coating applicator. For the purposes of this design, two options were preserved consistent with the latter definition of continuous. The first was the case where the substrate entered the vacuum continously, was transported through the active applicator area, and subsequently was removed, all at a constant rate. The second was the case where a large quantity of substrate was entered into the vacuum subsystem in coil or roll form, for example, and fed, from within the vacuum, to the applicator area. Both are "continuous" with respect to the applicator. The first is referred to as a "continuous-continuous" operation because both entry to the vacuum subsystem and to the applicator area are continuous. The second is referred to as "batch-continuous" because entry to the vacuum subsystem is in the batch mode whereas exposure to the applicator is continuous. With current vacuum technology, the latter batch-continuous mode is commonly encountered and often a more cost effective solution than attempting the more elaborate continuous-continuous approach. Thus, both approaches were examined in detail.

### 2.1.2 General Systems Options

There are two general approaches which could be adopted to achieve the design objectives. They include:

* a unit dedicated to a particular application
* an adaptive unit

In the latter category, there are two options which were considered:

* the discretely modular system
* the single flexible unit

These system options are shown schematically in Figures 3 to 6. The dedicated unit (Figure 3) would generally be designed to optimize the substrate transport subsystem for a particular substrate geometry and the disposition of the other subsystems as a function of this transport mechanism. Such an option would have the advantage of offering probably the minimum cost for a given application. While such a system would comprise vacuum, microwave and reactant gas feed subsystem components that would be transferable to other applications, change-over from one application to another would require considerable reconstruction. Thus, the cost would be much higher when applied to a wide range of applications which involved diverse geometries, i.e., the incremental cost per application would be higher that the other options.

A single flexible system (Figure 4) reduces much of the effort and cost involved in the change-over from one application to another. Through appropriate selection of the basic geometrical configuration, it can be designed to accommodate a wide range of substrate configurations. It can be built around a standard, proven industrial production system to enhance reliability. One such unit is the standard cylindrical vacuum evaporation coating unit which could be modified readily for LMP processing simply by adding an array of microwave windows around the circumference. Appropriate substrate transport mechanisms would be incorporated inside the vacuum chamber to expose the substrate to the plasma. Several transport mechanisms are shown schematically in Figure 5. They would be designed as separate inserts for the cylindrical chamber. While this type of unit would be flexible, it would present certain disadvantages. It would not readily accommodate long rod and tubular substrates. Large disks would present a problem in getting

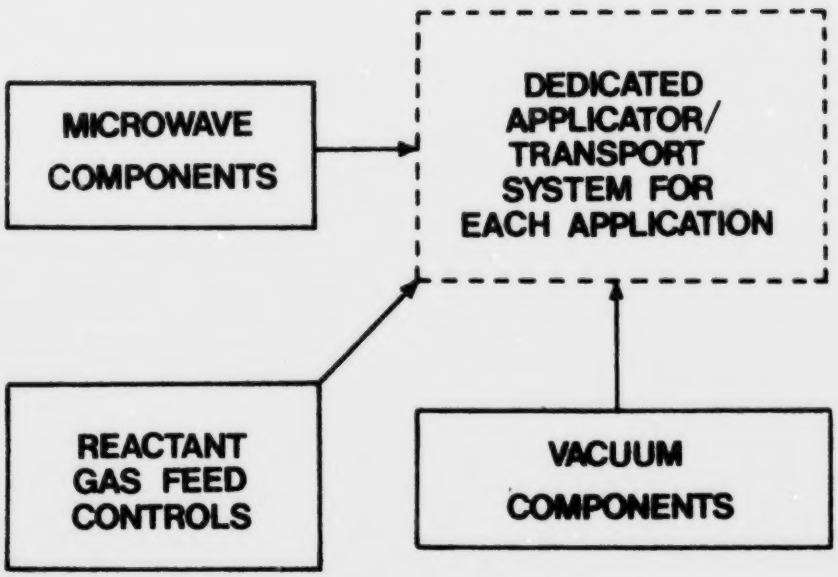



FIGURE 3. DEDICATED SYSTEM

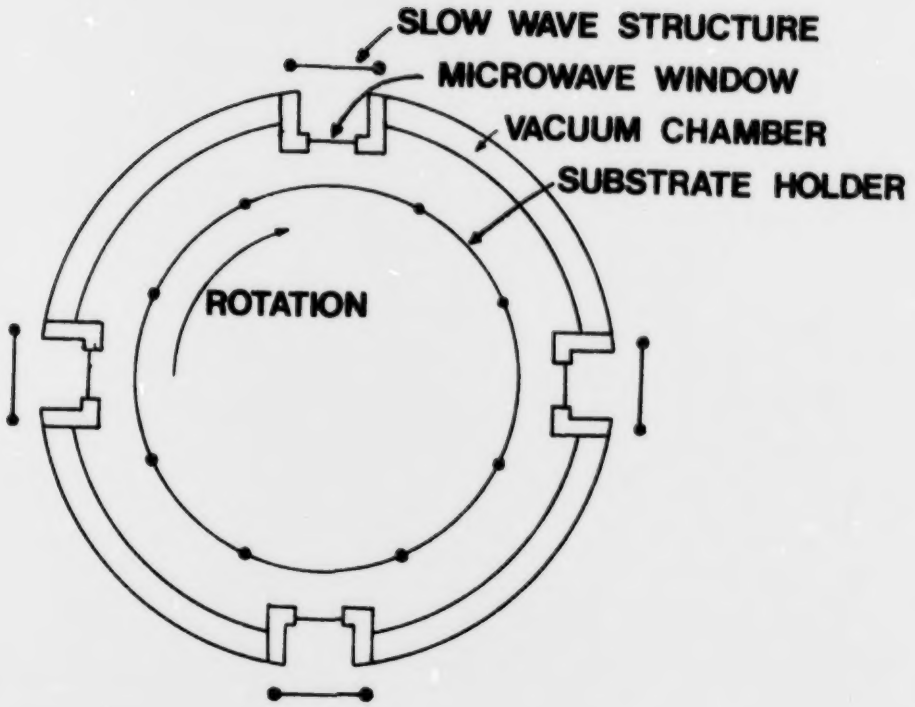
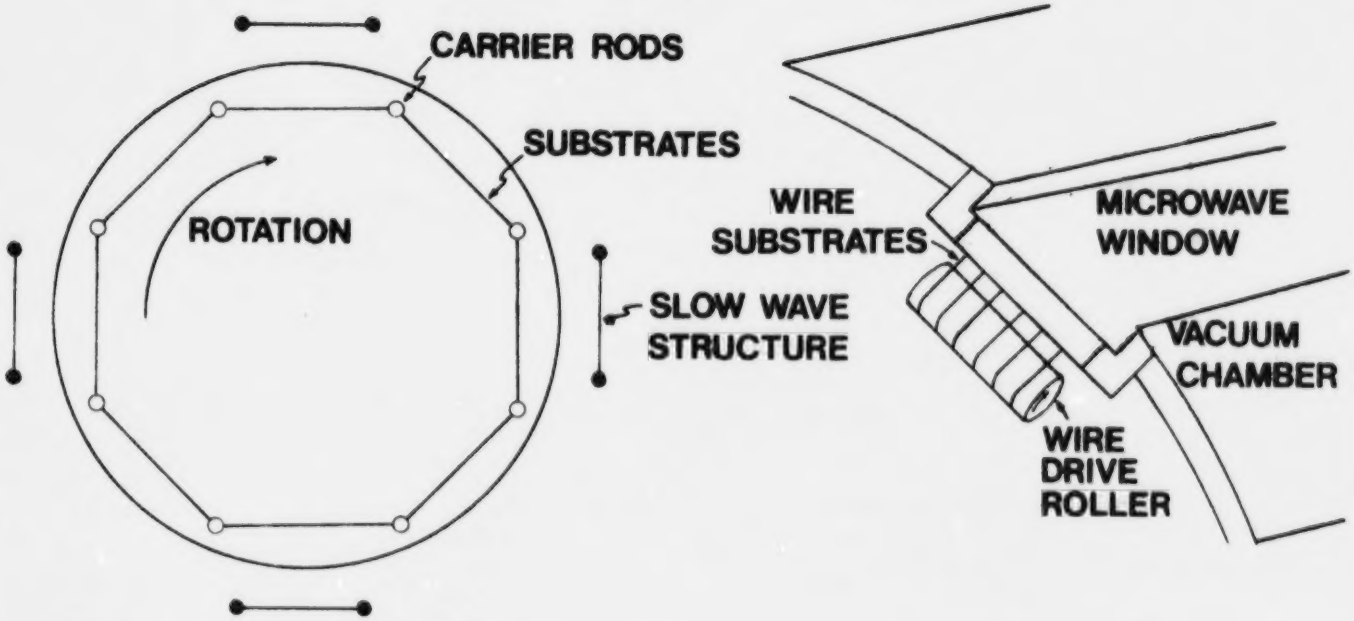
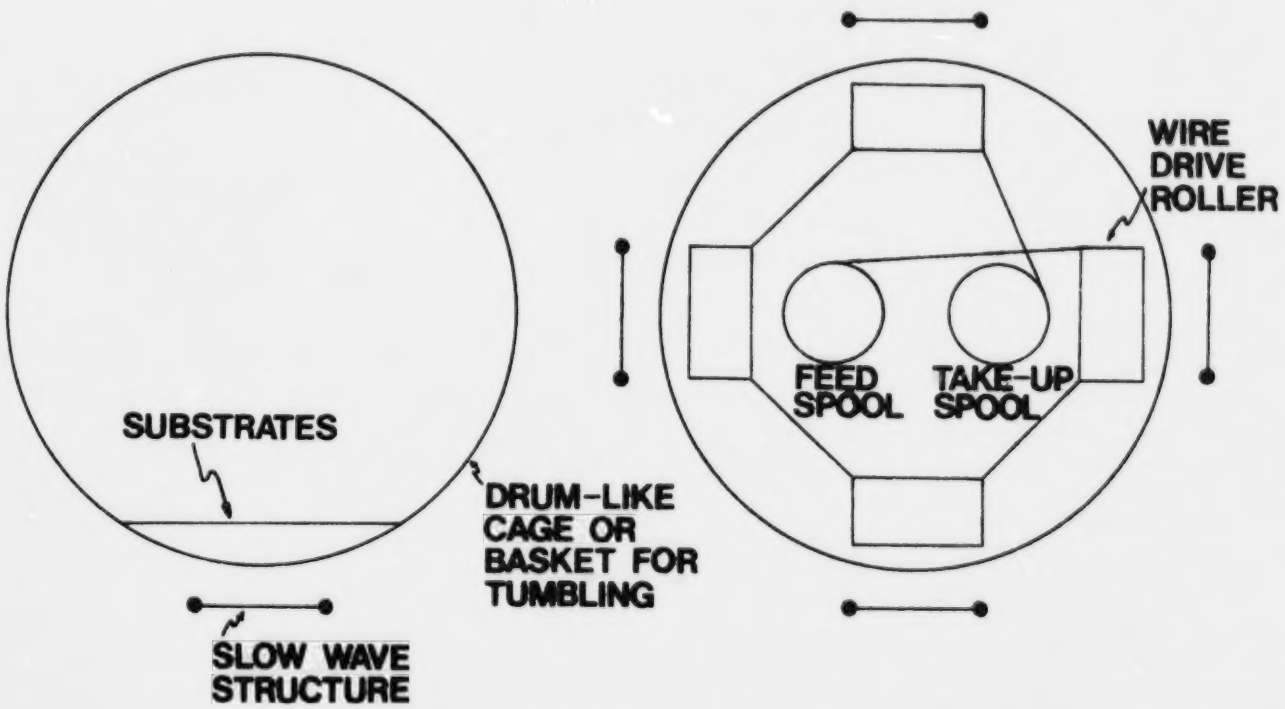



FIGURE 4. THE SINGLE FLEXIBLE SYSTEM




1) DISKS AND PLATES: SINGLE-SIDED




2) PARTS AND PARTICULATE

3) WIRES AND FILAMENTS

FIGURE NO. 5. SAMPLE SUBSTRATE HOLDER CONFIGURATIONS

their centers close to the window and the position of such substrates would vary from edge to center. Two-sided coating of flat substrates would be difficult in this type of unit. For high quality coatings the substrate goes through a horizontal position where particle contamination may be enhanced. Finally, the unit does not lend itself to continuous entry and exit of product.

The second adaptive option (Figure 6) involves complete modularity. It is based on two transport modules between which is placed the applicator module. Auto-entry and exit modules could be added later. Both the transport and applicator modules would integrate maximum commonality vis-a-vis a wide range of applications. It is anticipated that this design would be inherently simpler than be flexible cylindrical system above. It would comprise modules with rectangular cross-sections and could be operated either vertically or horizontally (Figure 7). The transport modules would have a common drive for a conveyor of discrete parts (with vibration for small parts and particulates), for pulleys or grooved drive rolls for wires and filaments, and for advancing long rods and tubes through the applicator. It could likewise drive a drum inside the applicator should this be more appropriate for particulates. In this configuration, positioning within the window is simpler and substrate-to-applicator distance is maintained constant. Extention to multi-applicator stages and to continuous entry and removal is simple. 100% vertical substrate movement is possible. A major disadvantage to this approach may be cost. The rectangular chambers are inherently more expensive to build than the cylindrical chambers.

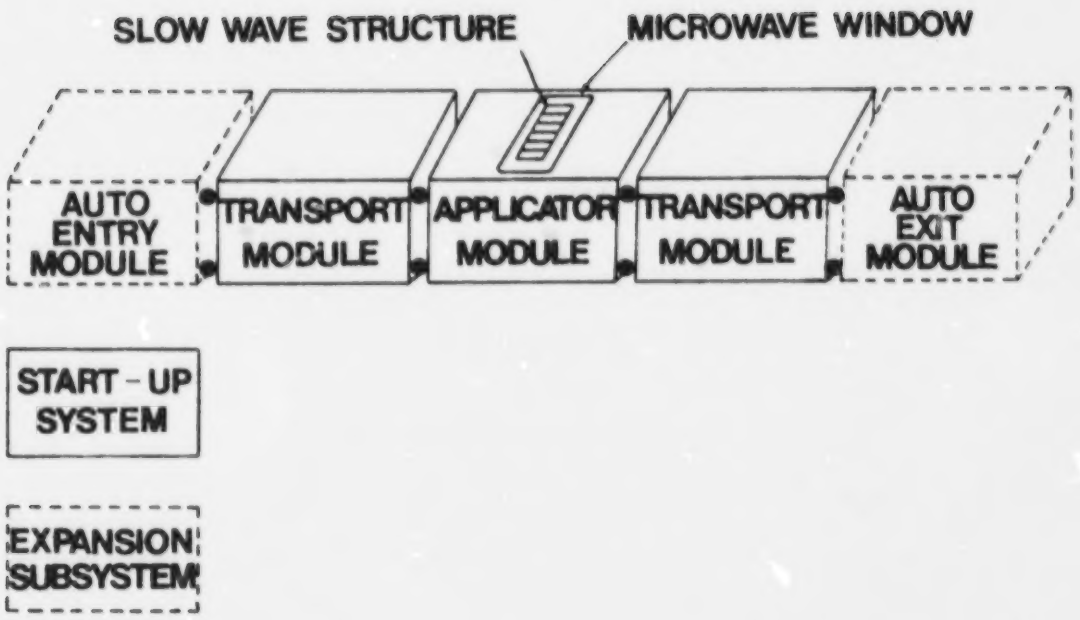
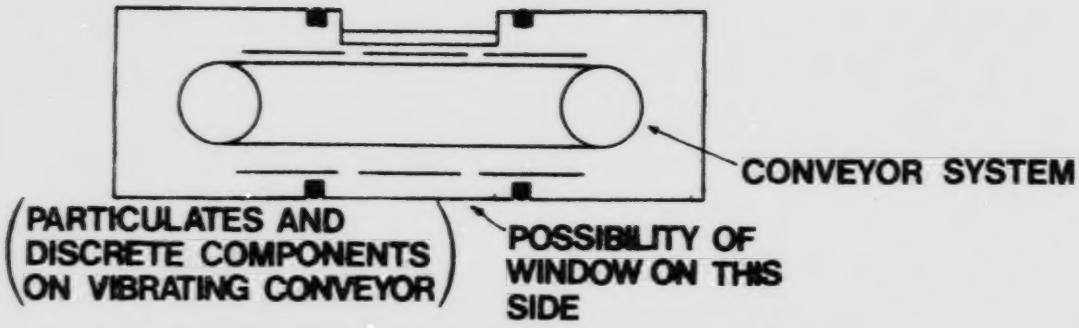
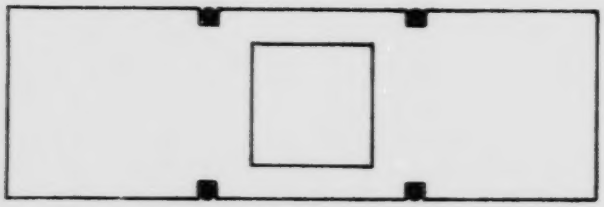


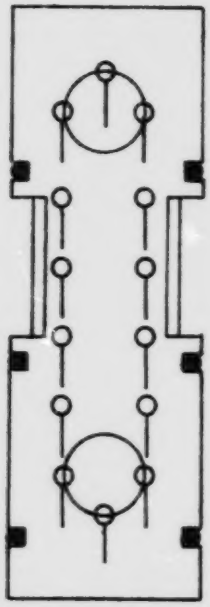

FIGURE 6. THE COMPLETELY MODULAR SYSTEM



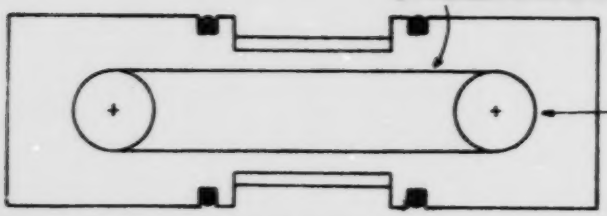

SINGLE-SIDED: FLAT SUBSTRATE-HORIZONTAL



SINGLE SIDED: FLAT SUBSTRATE-VERTICAL



DOUBLE-SIDED: FLAT SUBSTRATE




WIRE AND FILAMENTS

FIGURE 7. MODULAR SYSTEM ORIENTATIONS

## 2.2. THE DEDICATED UNIT

### 2.2.1 Selection of the Application

In keeping with the general objective of this project and its specific reference to wire coating and to major Canadian industrial establishments such as Canwirco, an agreement of cooperation was reached with Canwirco Ltd and its parent company, Noranda Ltd. Through this agreement it was possible to obtain industrially relevant parameters upon which to base a design. Although flexibility remained on objective, under this design approach the development and demonstration unit was optimized for wire coating on a continuous-continuous basis. Several meetings between representatives of the collaborating parties established major guidelines for the performance of the unit. Similarly, guidelines were established for the properties of the plasma polymer coatings produced by the unit.

### 2.2.2 Design Criteria

Process parameter criteria include:

* Continuous operation at variable line speeds up to a maximum of approximately 100 feet per minute.

* Capacity to handle magnet wire substrates with AWG sizes between 18 and 40 (corresponding to diameters between 1 mm and 0.09 mm).

* Control of substrate temperatures well in excess of 200°C.

Coating criteria include:

* Breakdown field of 300 volts/mil (approximately 12 M volts/m).
* Adhesion to the copper wire at least as strongly as conventional coatings (enamels, etc.).
* Thermal stability to approximately 500°C.
* Ductility of 20% elongation without failure.

### 2.2.3 Conceptual Design

Dedicated to continuous substrates, this unit was designed using four plasma reactors in series. In each reactor the substrate is cycled through the plasma several times. Using a staged vacuum, substrate feed and wind-up occur at atmospheric pressure. Each of the four reactors has independent monomer feed and substrate temperature controls. The process is completed by thermal conditioning of the plasma-coated substrate in an in-line oven.

### 2.2.4 Schematic Design

The unit dedicated to wires and similar continuous geometries such as filaments, tapes and webs is shown in Figure 8.

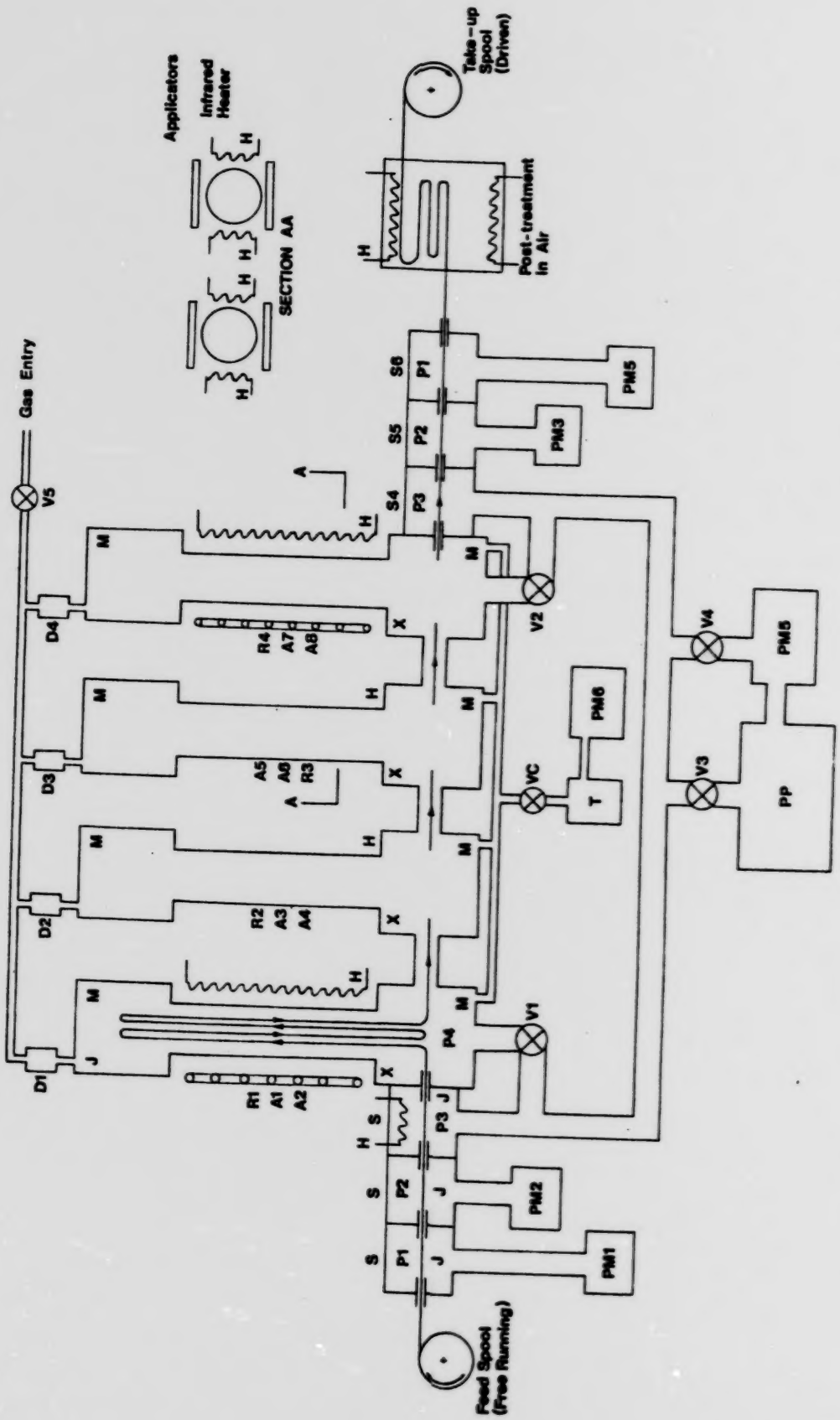



FIGURE 8. DEDICATED WIRE COATING SYSTEM

FIGURE 8

| | |
|---|---|
| S1 to S6: | Stepped vacuum entry and exit ports with dynamic seals. |
| PM1, PM4: | Mechanical pumps (could be combined into a single unit) |
| PM2, PM3: | Mechanical pumps (could be combined into a single unit) |
| PM5: | Mechanical pump |
| PM6: | Mechanical pumps for reaction products |
| T: | Trap for condensibles |
| PP: | Main vacuum pump |
| V1 to V5: | Valves |
| VC: | Controlled variable conductance valve |
| H: | Heating system |
| D1 to D4: | Flow meters |
| Section AA: | Set up of applicators and heaters around the reactor chambers |
| R1 to R4: | Reactor chambers |
| M: | Multi pass filament transport modules (10 passes per reactor) |
| P1 to P4: | Pressures in the various ports of the system |
| A1 to A8: | Microwave applicators (slow-wave structure) |
| X: | Temperature measurement locations |
| J: | Pressure measurement locations |

### 2.2.5 Detailed Design

Based on the application selected, namely continuous wire coating, a set of detailed design criteria were established. Figure 9 schematically divides the system into subsystems for design purposes.

#### The Substrate Transport Subsystem

The Substrate Transport Subsystem (block 1 in Figure 9) has components at both the front and exit ends of the system. In general, it was required to provide:

* continuous transport at a speed variable between 0 and 100 feet per min.

* capability to treat a range of different but geometrically similar products such as wire, tapes and ribbons, and narrow strip.

Both the winding speed and the tension in the transported product were to be controlled by motors on the feed and wind-up reels.

Just after entering the Vacuum Subsystem and immediately after leaving (blocks 2a and 2c in Figure 9) the product is pretreated and post-treated. Both are thermal treatments. In the pretreatment chamber, the objective is to raise the temperature of the substrate and to clean under vacuum. The temperature was to be controlled between 20 and 300°C. The temperature of the product was to be measured at the entrance to the reactor using a pyrometer. Pre-cleaning in air was to be effected by passing the substrate through felt pads and cleanliness evaluated by visual inspection only.

1- Substrate transport subsystem
2a Pretreatment subsystem
2b Vacuum subsystem
2c Post-treatment subsystem
3 Microwave subsystem
4 Reactant gas feed subsystem
5 Control and protection subsystem

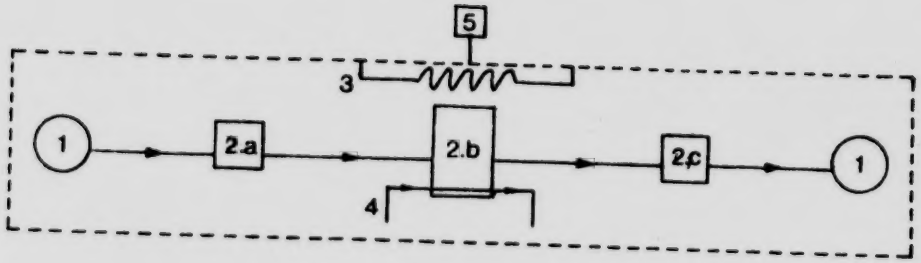



**FIGURE 9. SCHEMATIC DIAGRAM OF SUB-SYSTEMS**

The post treatment was a thermal treatment of the surface at atmospheric pressure as well as a controlled cooling operation with temperature as the variable to be controlled in this stage.

Design calculations were carried out to determine an optimal combination of reactor size and transport speed. They were based simply on the following equation:

$$L = \frac{v}{60} \frac{t}{R} \qquad (1)$$

where L = length of the plasma in feet.

v = streaming velocity of the wire in feet/minute.

t = coating thickness in Angstroms.

R = deposition rate in Angstroms/second.

The deposition rate R is an average value assumed attainable in the larger scale version under design here. In the laboratory, rates of up to 250Å/s are obtained for organosilicones on small sample surfaces ($4cm^2$). In these laboratory experiments the samples are placed in a small region of the plasma usually where it is most intense and the deposition rate is fastest.

In the larger development and demonstration unit the overall average rate will be somewhat lower although the design objective is to maintain the average rate as uniformly close to the optimum as possible.

Results of the computation are shown in Figures 10 to 12. Firstly, the length of the plasma was calculated as a function of the thickness/deposition rate ratio. The latter ratio corresponds to the residence time necessary to obtain a required thickness. A series of

curves covering the range of 5 sec. to 500 sec. is presented in Figures 10 and 11 where each curve is labelled with the streaming velocity of the wire. In Figure 12 the length of the plasma is shown as a function of the wire streaming velocity for a deposition rate of $R = \frac{10}{A}$ where $0.1<A<1$. If A = 0.2, the length required, for v = 150 ft./min, $\overline{t}$ = 3000 Å, is 140 ft. when the deposition rate is 50 Å/s.

The unit was designed to operate at streaming velocities up to 100 ft./sec. which, at a deposition rate of 50 Å/sec. would give a thickness of 3600Å. More substantial thicknesses can be attained for development projects by operating at lower speeds.

**The Vacuum Subsystem**

The primary function of the Vacuum Subsystem, in addition to the heating and cleaning operations outlined above, is to serve as a plasma reactor. It was to operate at a vacuum of .001 Torr or less continuously in a volume of 20 to 30 litres. The process parameters requiring control were the temperature, the pressure and the pumping rate of the vacuum pumps. To achieve the required residence time and substrate speed required that four reactors be used. A cylindrical geometry using quartz tubes was adopted.

The secondary function of the Vacuum Subsystem is to maintain the desired pressure gradient between atmosphere and plasma vessel; this is achieved with a serie of vacuum chambers, (entry and exit) each being separately pumped and communicating with the others via "dynamic seals"; the roles of the seals are first to permit free streaming of the product from entry to exit with the minimum strain and second, to restrict the flow of air between the chambers. First chamber (or the last) communicate with atmosphere; the dynamic seals are of course

real leaks and enough pumping speed is to be provided at each stage for achieving the necessary total pressure gradient and ultimate base pressure in the plasma vessel; there is no doubt that cost of the pumping units is the main part of the cost of the vacuum subsystem and it is evident this cost increases with specified pumping speed; in order to optimize the performance cost ratio, a short analysis is needed to determine the necessary pumping speed at each step of the staged vacuum. Very preliminary calculations have shown that 3 steps of staged vacuum would probably be enough and the schematic system used for analysis is shown in Figure 13:

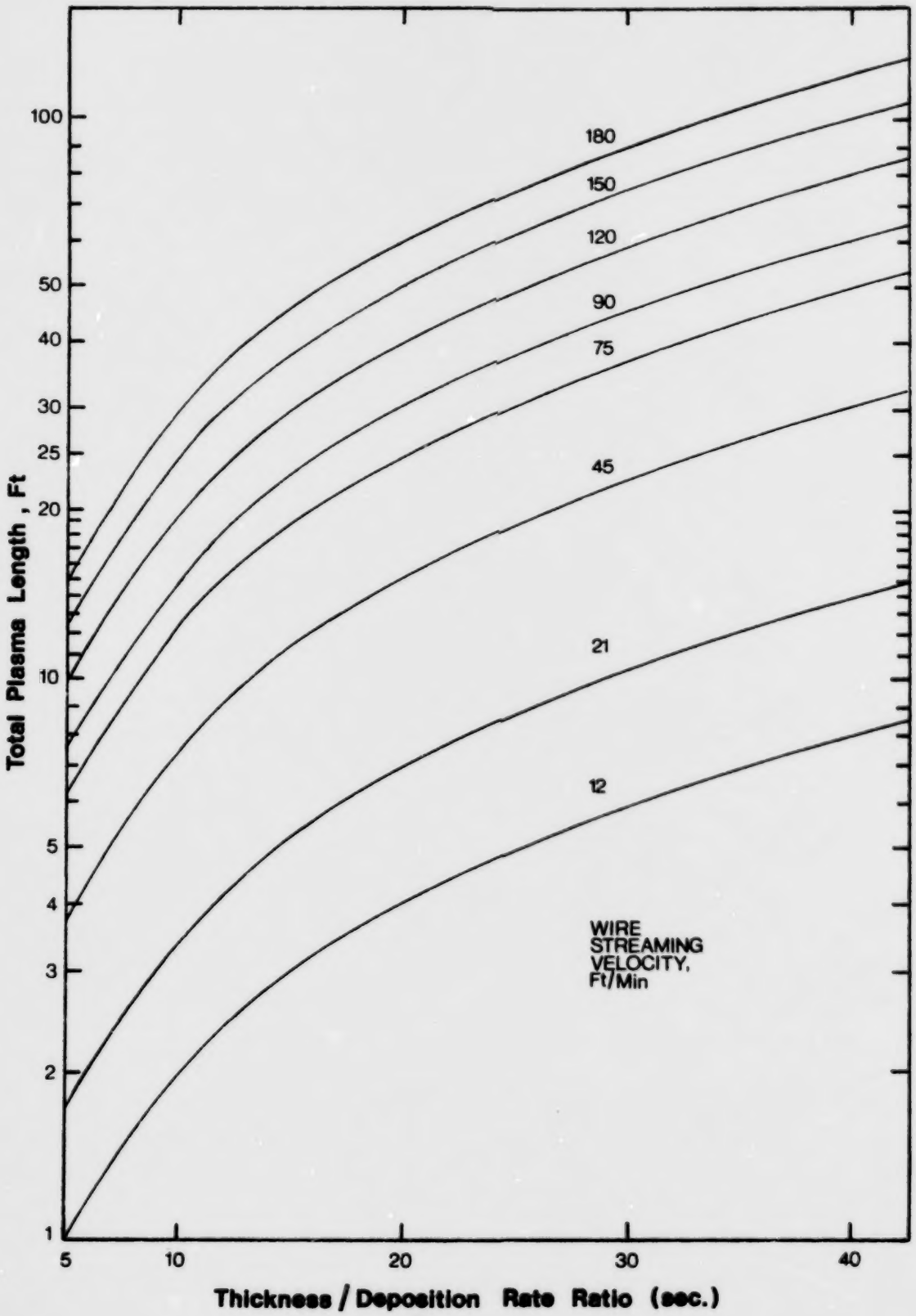
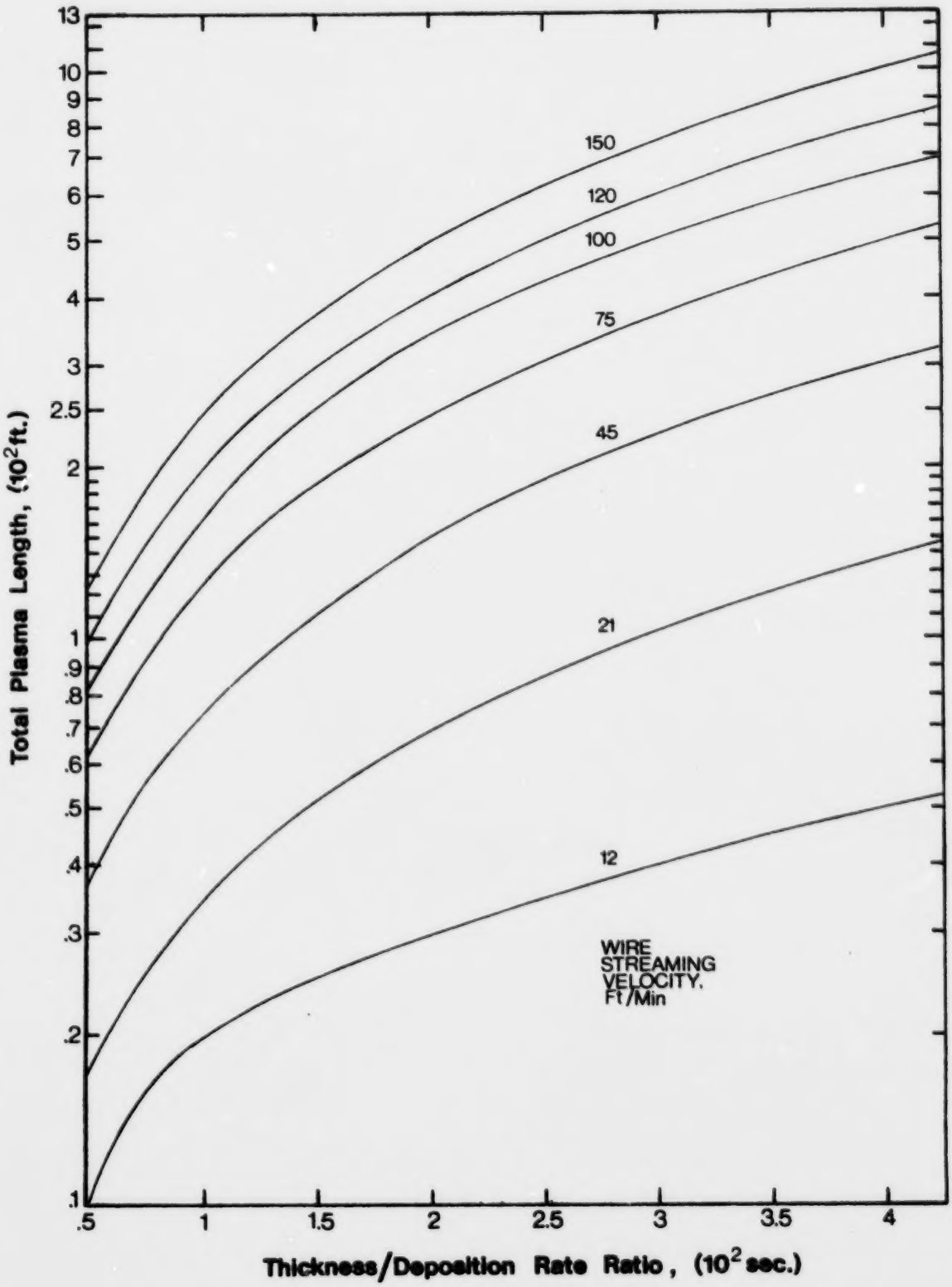

Total Plasma Length , Ft
100
50
40
30
25
20
10
5
4
3
2
1
180
150
120
90
75
45
21
12
WIRE
STREAMING
VELOCITY,
Ft/Min
5
10
20
30
40
Thickness / Deposition Rate Ratio (sec.)

**FIGURE 10.**


Total Plasma Length, ($10^2$ft.)
13
10
9
8
7
6
5
4
3
2.5
2
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
150
120
100
75
45
21
12
WIRE
STREAMING
VELOCITY,
Ft/Min
.5
1
1.5
2
2.5
3
3.5
4
Thickness/Deposition Rate Ratio, ($10^2$ sec.)

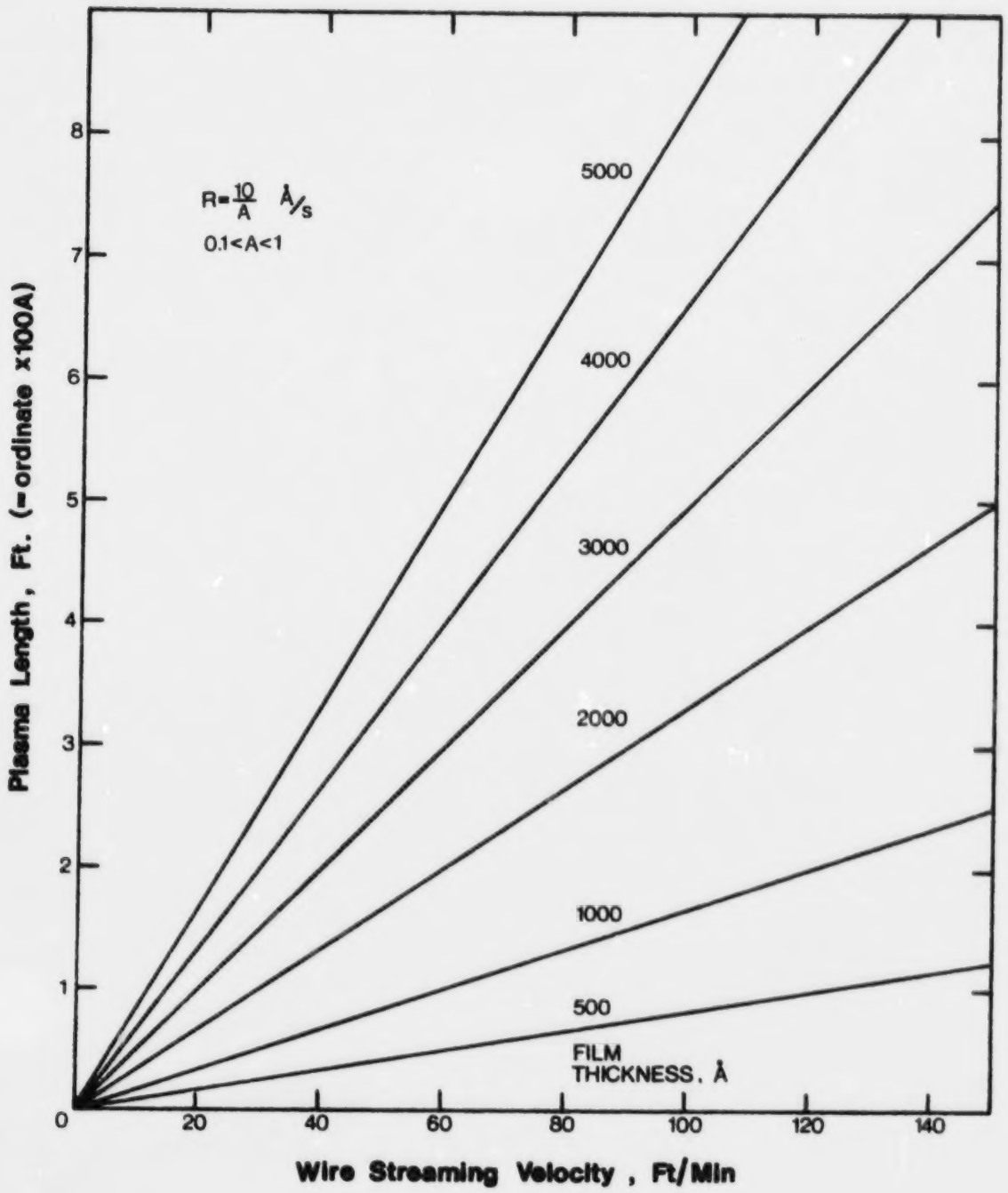

Plasma Length, Ft. (=ordinate x100A)
Wire Streaming Velocity, Ft/Min
R=10/A Å/s
0.1<A<1
5000
4000
3000
2000
1000
500
FILM
THICKNESS, Å
0
1
2
3
4
5
6
7
8
20
40
60
80
100
120
140

**FIGURE 12.**

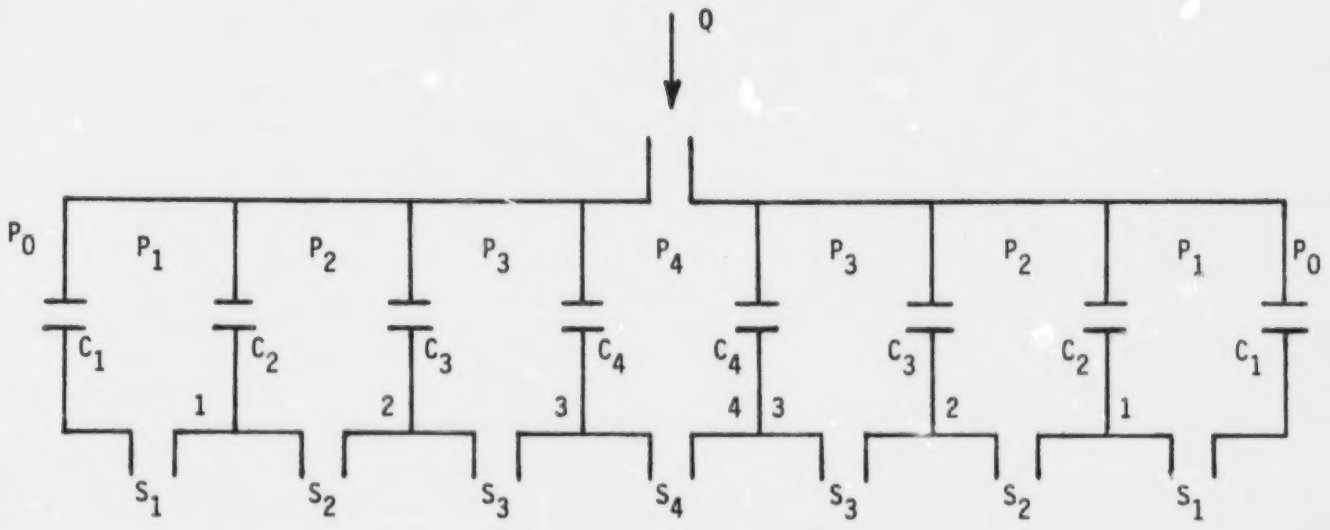



Figure 13 - Schematic system used for pressures determination

Chambers are identified by the numbers 1, 2, 3, 4, with associated respective pressures $P_1$, $P_2$, $P_3$, $P_4$; each chamber is evacuated by pumps with respective pumping speed: $S_1$, $S_2$, $S_3$, $S_4$. $P_0$ is atmospheric pressure. Q is flow of monomer during operation. $C_1$, $C_2$, $C_3$, $C_4$ are the conductances of the dynamic seals as indicated on the drawing.

The calculations outlined below give the ultimate pressures, but do not consider dynamics, i.e. time to reach those pressures; degassing, leaks (real and virtual) are neglected.

It is clear that there is a pressure "symmetry" around chamber 4. Operation is summarized as follows: during pump-down, wire is at rest through all sealing apertures; when base pressure is obtained, monomer is fed with flow Q and pumping speed $S_4$; wire breaking is simulated when all apertures are free from wire (the worst case), with monomer still flowing with flow Q:

System statics are described by the following equations:

$$P_4 = \frac{2C_4}{\alpha} P_3 + \frac{Q}{\alpha} \quad (2)$$

$$P_3 = \frac{C_3}{\beta} P_2 + Q \frac{C_4}{\alpha\beta} \quad (3)$$

$$P_2 = \frac{C_2}{\gamma} P_1 + Q \frac{C_3 C_4}{\alpha\beta\gamma} \quad (4)$$

$$P_1 = \frac{C_1}{\gamma} P_0 + Q \frac{C_2 C_3 C_4}{\alpha\beta\gamma\delta} \quad (5)$$

(6)

with

$$\alpha = S_4 + 2C_4 \quad (7)$$

$$\beta = S_3 + C_3 + C_4 \left(1 - \frac{2C_4}{\alpha}\right) \quad (8)$$

$$\gamma = S_2 + C_2 + C_3 \left(1 - \frac{C_3}{\beta}\right) \quad (9)$$

$$\delta = S_1 + C_1 + C_2 \left(1 - \frac{C_2}{\gamma}\right)$$

These equations are the most general ones which calculate each pressure $P_i$ as a function of the monomer flow Q.

Each pressure $P_1$, $P_2$ and $P_3$ may be expressed as a function of $P_0$ and $P_4$ only:

$$P_1 = P_0 \frac{C_1}{D} (vw - C_3^2) + P_4 \frac{C_2 C_3 C_4}{D} \quad (10)$$

$$P_2 = P_0 \frac{C_1 C_2 w}{D} + P_4 \frac{C_3 C_4 u}{D} \quad (11)$$

$$P_3 = P_0 \frac{C_1 C_2 C_3}{D} + P_4 \frac{C_4}{D} (uv - C_2^2) \quad (12)$$

with:

$$u = S_1 + C_1 + C_2 \quad (13)$$

$$v = S_2 + C_2 + C_3 \quad (14)$$

$$w = S_3 + C_3 + C_4 \quad (15)$$

$$D = uvw - wC_2^2 - uC_3^2 \quad (16)$$

Equations 2-16 are the most general ones and depending on particular applications they can be greatly simplified when, for instance, ratios of the type S/C are >>1.

A first set of calculations was performed with the following conditions:

1) $S_1$ = 11.8 l/s
   $S_2$ = 6.4 l/s
   $S_3$ = 400 l/s
   $S_4$ = 0.7 l/s
   Q = 1 Torr x l/s

2) These speeds are assumed to be effective at the ports of each chamber, which means that conductances between pumps and chambers are negligeable.

3) Dynamic seals are assumed to be thin apertures with diameter 1.4 mm: this geometry is the most simple and the least expensive, and is expected to be mechanically acceptable for wire with diameter up to 1 mm.

4) The limits given in the table correspond to calculations made with the lowest and highest conductances estimated for the dynamic seals. The highest conductance for a thin aperture corresponds to the critical flow and if A is the area of the aperture, one has

$$C_H\ (l/s) = 20.0\ A\ (cm^2) \qquad (17)$$

Lowest conductance corresponds to the molecular flow and one has, for the same aperture

$$C_L\ (l/s) = 11.6\ A\ (cm^2) \qquad (18)$$

It has furthermore been assumed that $C_1$ was always the critical conductance $C_H$ because chamber 1 is open to atmosphere $P_0$.

5) When the wire is present, the effective area of the dynamic seal is no longer a circle with diameter 1.4 mm and area A, but now becomes an annulus with outer diameter 1.4 mm and inner diameter 1 mm (in the case of wire AWG 18); we however make the approximation that the conductances depend only on the "open" area, so that the values $C_H$ = 20 A and $C_L$ = 11.6 A apply with A being the area of the open annulus.

6) In Table I, pump-down is simulated with wire in place at all apertures, operation is simulated with air flow of 1 Torr x l/s in chamber 4, and wire breaking is simulated by full opening of all the dynamic seals, the flow of mononer staying at its nominal value (these are the worst case conditions).

TABLE I

| Pressure (torr) | Pump-down | Operation | Wire breaking |
|---|---|---|---|
| P1 | = 10 | = 10 | = 20 |
| P2 | 0.1 to 0.2 | 0.12 to 0.21 | 0.5 to 0.85 |
| P3 | $2.5 10^{-5}$ to $8.10^{-5}$ | $2.10^{-4}$ to $4.5 10^{-4}$ | $5.3 10^{-4}$ to $1.2 10^{-3}$ |
| P4 | $2.5 10^{-5}$ to $8.10^{-5}$ | 1 | 0.9 |

An experimental set-up was built and tests performed by CVE under contract (see appendix A) in order to verify the assumptions used in the calculations. Wire breaks and pump-down only were tested but these tests are sufficient to draw useful design conclusions.

Testing was carried out under the following conditions.

$S_1 = S_2 = 5.2$ l/s
$S_3 = 50$ l/s
$S_4 = 0$

The seals were made from viton sheet (width 1/8") and the aperture had a nominal 1.4 mm diameter. Wire with a diameter of 0.85 mm was used for the experiments.

Calculations using the above test conditions gave the following pressure values in the case of pump-down:

$$P_1 \simeq 27 \text{ Torr}$$
$$0.55 < P_2 < 0.92 \text{ Torr}$$
$$1.2 10^{-3} < P_3 < 3.5\ 10^{-3} \text{ Torr.}$$

The corresponding test results found in CVE report are:

$$5 < P_1 < 13 \text{ Torr}$$
$$0.045 < P_2 < 0.085 \text{ Torr}$$
$$7.3\ 10^{-5} < P_3 < 9.1\ 10^{-5} \text{ Torr}$$

The limits correspond to different positions of the wire in the seals and as the seal is deformable, we should take the lower limit, corresponding to a centered stationary wire, to compare with calculations. One flexibility of the equations is that we can inject into the calculation of the second stage the result of the experiment for the first chamber; then we get

$$0.103 < P_2 < .174 \text{ Torr}$$
$$2.3\ 10^{-4} < P_3 < 6\ 10^{-4} \text{ Torr}$$

This exercice shows that most of the disagreement between theory and experiment comes from the first conductance but that the others contribute significantly as well. Another interesting calculation shows that, giving to the first conductance the "molecular flow" value $C_L$, does not remove completely the discrepancy.

This is not surprising because the approximation made to consider each seal as a very thin aperture is far from the experimental reality where each seal is more or less a channel: in fact we have already mentioned that the viton sheet used for fabrication of the seal was 3.1 mm thick, so that the ratio between length and characteristic "open" dimension (diameter of the aperture with no wire, or clearance when wire is in place) is about 11 for 0.85 mm dia. wire in the seal. The geometry looks more like a thin "annular" tube than a thin aperture. The use of the thin aperture approximation in the critical regime was however justified because we have found neither theoretical nor experimental work applicable to this geometry and because it was found to work fairly well to correct some results found in the literature (with a rectangular and not circular geometry, however).

Another interesting result from the CVE study is the comparison between the results with 1.4 mm dia. seals and 1.2 mm dia seals. The strong reduction observed in the conductance $C_1$ with a relatively small decrease of seal diameter supports the discussion given above. It would be probably very useful to consider a series of seals in which the first is tighter than the others.

The results of the experimental study made by CVE show that our approximations introduced in the calculations made for evaluating the pumping speeds needed at each stage are very conservative. We can therefore conclude that the pumping speeds used in the simulation would have handled very comfortably the gas loads of the pilot plant, even in the worst case of wire breaking on the air input side, for all sizes of wires up to 1 mm diameter; this would have been probably true for very thin small width ribbon like 1/4" magnetic tape, too, with still simple dynamic sealing geometry.

## The Microwave Subsystem

The Microwave Subsystem comprises the generator, the slow wave structure and the microwave accessories required to link the two. A total generating capacity of 10kW was selected, variable between 0 and 10kW at the ISM frequency of 2.45 GHz. It would be necessary to control the input and reflected power.

The design of the slow wave structure establishes the intensity of the electric field in the plasma and the efficiency with which power is coupled into the reactant. Such variables as the distance of the slow wave structure from the reactant and substrate and the angle between the slow wave structure and the microwave window were criteria requiring specification. In this design each reactor would be serviced by two slow wave structures and each pair of structures by a single 2.5kW generator. The structure would be the patented ladder type approximately 1.0 m in length and 8 cm in width.

Microwave accessories were necessary to carry power from the generator to the slow wave structure as well as to have the capability to absorb the unused power or the total power through control of the incident and reflected power.

Reactant Gas Feed Subsystem

The objective of this subsystem was to obtain a uniform distribution of reactant within the reactor with the possibility of using a wide variety of reactant gases and providing accurate control of the gas pressure and flow rate.

Control and Protection Subsystem

This subsystem would comprise the control capability for the principal process variables outlined above. Also, protection methods for the risks of implosion, radiation and residual gas toxicity were considered.

### 2.2.6 Evaluation

In a number of important respects the property requirements for coatings in the wire coating application posed significant challenges to plasma-polymers and to reactors suited for their production. Such polymers, being usually highly crosslinked, are excellent barrier films and adhere strongly to substrates. However, because of the inherent crosslinking feature, their flexibility tends to be limited. Further, even LMP polymerization processes, which are typically 10-20 times faster than lower-frequency discharged reactions, are well suited to produce coatings in a thickness range near or below 1 m. In the present application, thicker films (e.g. 5-10 μm) would presumably be required to meet electrical breakdown specifications hence necessitating relatively long plasma-polymers needed for the current application, would lead this research team into as yet unexplored areas of plasma polymer science, no information yet being available on the physical and mechanical properties of such thick films produced via the LMP route.

The above noted challenges, and others, necessitated a product-development research program to be carried out simultaneously with the design program. Results of the research and development work will be reported separately. In summary, it was shown that:

- Plasma polymers (notably those based on organo-silicon monomers) capable of withstanding temperatures up to 500°C, could be produced with ease.

- "Thick" films (in excess of about 3 μm) with good cohesion, could be produced by carefully programming power density and temperature during plasma deposition. The adhesion of these films to the substrate, while superb at thicknesses below 1-2 μm, was impaired at higher thicknesses, and tended to vary somewhat with the chemical nature of the substrate.

- "Thick" films, though stable under mild deformation, would not readily withstand severe deformations, such as encountered in twisting and twining of wires.

It became obvious that the solution to these technical problems must precede an implementation of an apparatus dedicated to wire coating. Furthermore, since start-up of the design-phase program it became increasingly clear from on-going exploratory research on LMP processes, that large-scale application other that magnet wire coatings were in the offing. While some of these, such as the treatment of polymer and glass fibers, might make use of apparatus along the lines of the dedicated wire coating design, others - involving optical lenses and optical disc technology - (i.e. discrete components) would require a radically different plasma reactor. Thus, the limitations of the design began to appear as punitive.

Nevertheless, significant progress had been made toward the design of such a facility and, indeed, that design could well serve such ends as the deposition of a pinhole-free primer coat on magnet wire. Alternatively, the design could well be applied for the treatment of numerous continuous - web substrates including metal, glass or polymer fibers.

Thus, once this design was developed to this stage and evaluated in its own right and vis-a-vis the results of a parallel R and D study it was decided to proceed to a more flexible and adaptive design. Thus, more detailed design and cost analysis were not carried out.

## 2.3 THE ADAPTIVE DESIGN

### 2.3.1 Conceptual Design

The basis of this adaptive design approach was to select a commercial vacuum system of the type used for other vacuum coating applications and to use it as a basis for the LMP process. Thus, the basic Vacuum, Substrate Transport and Reactant Gas Feed Subsystems would be off-the-shelf equipment modified to provide microwave windows and applicator assemblies. Through the use of simple geometrical designs and substrate transport systems the full range of substrate geometries identified in Section 1.4 could be addressed readily with a minimum of modification.

### 2.3.2 Schematic Design

Two options are possible under the adaptive design, both of which are based on "off-the-shelf" equipment manufactured by Leybold-Heraeus (L-H)*:

(i) cylindrical vacuum chamber (A650H to A2500H series), or
(ii) chamber of flat, rectangular section (Z400 to Z600 series).

In appendix B, we show photographs derived from L-H and High Vacuum Systems literature. In this project we have focussed our attention on the cylindrical vacuum chamber (L-H model A900H).

As is evident from the details in Appendix B, the basic vacuum chamber houses a substrate "rack", which in presently available form accepts discrete substrates of various geometries, be these simple or complex. The price quotation offered by Leybold-Heraeus for a pilot facility includes this type of rack. A second rack (see figure 5) will accommodate continuous substrates, including multi-strands of magnet wire in a range of diameters, as well as other forms of continuous substrates, e.g. web, filement, tape, etc. A detailed costing of this second rack has not yet been obtained; during recent discussions with L-H in Germany it was suggested that we would be best advised to seek this from a manufacturer specialized in this kind of product.

* Note: L-H equipment is cited here because we happen to be best documented for this manufacturer; this does not imply a priori commitment to L-H as a potential supplier.

A listing of such Companies, for diverse items of the pilot facility, is included at pertinent points of Appendix C.

Appendix B shows in sketch form, modifications to the A900H needed for LMP applications, in particular wire coating.

### 2.3.3 Detailed Design

The treatment of discrete substrates (e.g. lenses, disks, turbine blades, fasteners, etc.) clearly involves a batch operation. According to the experience and recommandations of Leybold-Heraeus technical staff, the treatment of continuous substrates on a "batch-continuous" basis should be strongly considered, with substrate feed and wind-up equipment all housed within the same vacuum chamber. Elimination of the vacuum lock of the dedicated unit greatly simplifies the operation of a basic pilot unit and reduces its cost. Most importantly, it provides the desired flexibility of application lacking in the preceding design because an LMP unit for continuous air-to-air operation could only be designed for substrates of closely specified geometry. Significant deviations from that geometry (for example a significant change in wire diameter within the 18-40 gauge range pertinent to the wire coating application) would require appreciable changes in pumping capacity, the shape and size of entry and exit ports, etc.

The more general applicability of the adaptive design would permit credible demonstration of the LMP process for wide range of industrial applications and would generate the necessary data base on which to tailor, construct and operate industrial-scale units for each specific application.

Design requirements are outlined in detail in the letter of G. Archambault (01-21-82) to Leybold Heraeus which was also sent to other suppliers. Responses from three suppliers and the Archambault letter are appended in Appendix D. They provide detailed descriptions of the systems proposed and recommendations.

### 2.3.4 Cost Analysis

The cylindrical Leybold unit is quoted at 550,000 DM or approximately $330,000 (exchange rate 0.6, march 1982). This is exclusive of the microwave system and the wire transport system. On the other hand, it includes a high vacuum pumping capability which is not required for the LMP system. The microwave system would involve a cost of $50,000 based quotations. Additional microwave fixturing, including the slow wave structures based on past acquisitions at Ecole Polytechnique, is estimated at $30,000 or roughly the cost of the additional pumping capacity in the Leybold quotation. Thus the total system cost is estimated at $380,000. While a system at that price would be able to treat a variety of discrete parts, an additional $100,000 would be required to incorporate transport mechanisms for wires and filaments bringing the price to $480,000. High Vacuum Systems Inc. estimate $250,000 to $350,000 for their response to the design requirements. Engineering costs of $21,500 and microwave and filament transport costs bring the total possible cost to $371,500 to $471,000. In the case of the rectangular chamber, the wire substrate transport system would be less expensive and is estimated at $50,000. CVE Limited estimates at $222,500 less filament and wire transport, gas feed mechanism and microwave, again giving a total in the $370,000 to 380,000 range. However, their quotation does not suggest that they have examined the problem in as much depth as the other two respondents. Thus, a budgetary estimate of the order of $500,000 seems in order for the adaptive development and demonstration unit.

### 2.3.5 Construction Schedule

Delivery of the vacuum system with LMP modifications is estimated at 30 to 32 weeks. Assembly of the latter unit and its peripheral microwave accessories is estimated at 8 weeks. An additional 6 weeks for debugging and start-up brings the total time to operations to 46 weeks.

### 2.3.6 Evaluation

Regardless of the design option selected, the wire coating application is the most complex of the range of substrate geometries under consideration. In the cylindrical configuration, it would involve up to eight very complex mechanisms, one for each window. Problems of tensioning and controlling the operation of several such mechanisms would be difficult and present overall reliability problems. On the other hand the overall cylindrical geometry is simpler from a structural viewpoint.

The rectangular configuration does carry with it a structural penalty which significantly adds to cost. However, it does provide for more modularity and thus flexibility. It operates with flat substrates in a fixed orientation, either horizontal or vertical. In the cylindrical, the substrates rotate from horizontal to vertical while transported on the substrate rack. Transport mechanisms in the rectangular system can be made simpler, for vertical transport, the preferred orientation for quality coating.

Thus the cylindrical geometry is indicated for lowest entry-level cost for a limited number of applications exclusive of wire and filament substrates. The rectangular configuration is recommended when the number of applications is likely to be large and the range of applications is likely to include filamentary tape and web substrates.

# 3. TECHNICAL DISCUSSION

## 3.1 TECHNICAL COMPROMISES

A number of technical features were considered, modularity, flexibility, complexity of mechanisms, and substrate orientation. All are optimized in the rectangular configuration. It provides the opportunity for the greatest simplicity and maximum flexibility and adaptability from the technical point of view at a cost penalty as discussed below.

## 3.2 ECONOMIC COMPROMISES

A number of non-technical considerations must be considered in the design of an engineering system of the scale of the development and demonstration system under consideration in this report. These include cost and the range of applications (market) as well as the role the unit is to play in penetrating the market. As information on these parallel non-technical areas developed during the project along with technical information on parallel R & D projects, it was possible to make certain major decisions and changes in what was considered an optimal approach during the course of the project.

Both technical and economic (market) considerations suggested that the wire coating application was not the best target to aim for in this project. The discrete parts markets are more diverse and simpler to handle. The risk involved in the investment in the system would be minimized by spreading it over a wider range of potentially technically feasible projects. From a financial standpoint this also offered the possibility of getting funding from several potential users rather than a single source and was also an important consideration.

Selection of the optimal design concept must be made with due consideration of both entry level cost for one or a limited number of applications and overall cost for the full capability to treat the full range of major potential applications. In this regard it may be necessary to incur a higher initial cost for modularity to reduce subsequent costs of adaptation from one application to another. Thus, although the two equipment suppliers who have analyzed this requirement have recommended a rectangular configuration, it is somewhat more expensive than the cylindrical for discrete parts.

## 4. CONCLUSIONS AND RECOMMENDATIONS

This project has examined a series of design options for a large-volume microwave plasma facility for metal passivation. It has presented the engineering options in both technical and economic contexts. The decision on selection of an optimal design is not purely a technical one but must also be considered as a function of the range of applications and the primary target applications. Thus, business planning data are also necessary in making final choice. However, the report presents data on three key options and their relations to the economic variables of market and cost.

In summary, the optimal technical choice is the rectangular adaptive unit. Should minimal cost and a limited range of applications which does not include treatment of continuous filamentary, web, and similar substrates be dictated by the business plan the cylindrical adaptive unit is recommended. A unit designed specifically for and dedicated to a single application would not be cost-effective.

### Recommendations

1. Potential LMP applications should be ranked in order of commercial importance for the next 3 to 4 years and technical complexity identified.

2. The minimum configuration with maximum commonality for start-up and the additional modifications required over the full 3 to 4 years period should be defined to establish total 3 to 4 years program costs and benefits for both cylindrical and rectangular configurations.

3. A decision to proceed should then be made by combining the above commercial information and the technical, cost and design data presented in this report.

## APPENDIX A

Page

- CVE Study proposal ..... 42

- Experimental results ..... 43

CVE
Limitée

2755 DE MINIAC, ST-LAURENT, QUÉ. H4S 1E5 • TÉLÉPHONE: (514) 332-1025 • TÉLEX: 05-825687

October 13, 1981

C.N.R.
750 BelAir
Montreal, P.Q.

Attn: M. A. Adnot &
M. Archambault

STUDY PROPOSAL

But: Faire une étude de faisabilité pratique sur le sas d'entrée pour le procédé LMP en continu.

Equipment to be used in study:

The chambers will consist of 3 crosses, 2 macrovac and one stainless steel, a 3ft.storage chamber, 4 dynamic joints, 3 T.C. gauges, one ion gauge, 4 mechanical pumps, one diffusion pump, and other incidentals as required.

The study is designed to show the size of pump necessary to maintain given levels of vacuum in each of the chambers when these are interconnected by orifices of different sizes. The test will be carried out with at least two sizes of orifice. A further test will be done to show the effect of no wire in the system, and a test will show the effects of moving wire.

A detailed report will be issued showing pictures and diagrams of the test system, the orifices, and the results for each test performed.

Total cost for the study including delivery of the report will be $2865.00.

Time to supply the report will be 2 months from receipt of order.

Trusting the above complies with your requirement, we remain,

Yours very truly,

CVE LIMITEE

M. Michaels

BUT: Etude de faisabilité pratique sur le SAS d'entrée pour le procédé LMP continu.

SOMMAIRE DE L'ETUDE : Il s'agit de déterminer les vitesses de pompage nescessaires à chaque étages d' un système expérimental simulant les conditions qui pourront possiblement être rencontrées sur un système de production.

MONTAGES: Pour le montage du système complet; voir fig.1
Pour Montage des joints d'étanchéité; voir fig.2

MATERIELS UTILISES:

| Descriptions | Model | Manufacturier | Remarques |
|---|---|---|---|
| 1 pompe mécanique | ZM2004 A | Alcatel | 3.2 cfm. |
| 3 pompes mécaniques | ZM2012 A | Alcatel | 11 cfm. |
| 1 pompe mécanique | ZM2008 A | Alcatel | 7.0 cfm. |
| 1 pompe à diffusion | PVMF-11 | CVC | 100 l/sec |
| 1 jauge thermocouple | GTC-361 | CVC | ----- |
| 3 jauges thermocouples | 275-092 | Granville-Philips | ----- |
| 1 jauge à ionisation | 280-004 | Granville-Philips | ----- |
| 1 Trappe à Azote liquide | ----- | CVE | ----- |
| 1 vanne à ajustement fin | ----- | Nupro | ----- |

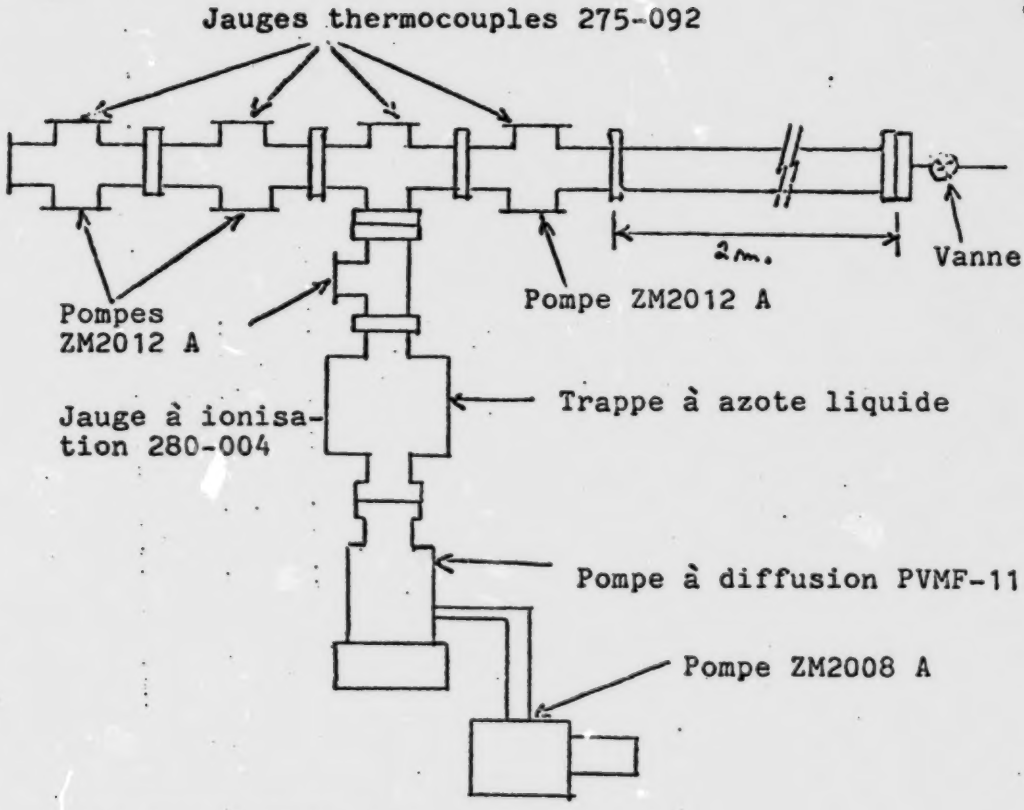
En plus de ces composantes, un certains nombres de croix d'adapteurs et de brides à montage rapides ont dû être employé.

Il est très important de noter que le choix du matériel doit s'effectuer avec beaucoup de précautions. Voici quelques uns des points à considérer:

- -jaugethermocouple: doivent fournir une bonne précision sur les plages couvrant la pression atmosphérique à $10^{-3}$ torr.
- jauge à ionisation: doit couvrir convenablement les pressions de $10^{-3}$ à $10^{-7}$ torr.
- Pompes mécaniques: capacité de supporter des cycles très rapide de variations de pressions

Vous trouverez, joint à ce rapport, les informations techniques concernant la plupart des appareils décrits ci-haut.

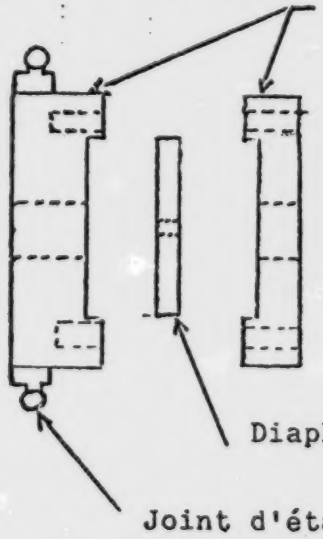
SCHEMA 1.




Voir aussi photo 1 et 2

SCHEMA 2.

Voir photo 3 et 4




Un joint de ce type est monté entre chaque étage. Sa fonction est de réduire au minimum l'influence de la pression de l'étage voisin.

PARTIE I PRESSION VERSUS VITESSE DE POMPAGE AU PREMIER ETAGE

Puisque le premier étage est celui qui devra assurer la plus grande différence de pression il est important de voir de quel facon la vitesse de pompage affectera la pression. Le tableau suivant donne les résultats obtenus pour 2 vitesses de pompage.

| VITESSE DE POMPAGE | PRESSION (torr) | |
|---|---|---|
| | sans fil | avec fil* |
| 3.2 cfm. | 50 | 8 à 15 |
| 11 cfm. | 25 | 3 à 10 |

* La pression de la chambre lorsque le fil y est introduit est fonction du positionnement du fil par rapport au centre du joint d'étanchéité.

Les résultats du tableau précédent sont valables dans les conditions suivantes: Diamètre du fil: 0.85 mm
Diamètre du diaphragme: 1.4 mm

PARTIE II ESSAIS 1

De la partie I nous avons déterminé qu'il sera préférable d'utiliser une pompe de 11 cfm. de façon à obtenir une pression suffisament réduite dans le premier étage du système.
Le but principale de cette manipulation est de s'assurer que, quoiqu' il arrive, la pression au troisième étage rest dans les limites permettant le fonctionnement d'une pompe à diffusion. Le tableau ci-bas donne un aperçu des résutats obtenus dans les différents étages.

| ETAGE 1 | | ETAGE 2 | | ETAGE 3 | |
|---|---|---|---|---|---|
| avec fil | sans fil | avec fil | sans fil | avec fil | sans fil |
| 5 torr | | .09 torr | | .015 torr | |
| 5 torr | | | .330 torr | .019 torr | |
| 5 torr | | .09 torr | | | .02 torr |
| | 25 torr | | 1 torr | | .08 torr |
| | 25 torr | .330 torr | | | .042 torr |

Conditions dans les quelles ces résultats ont été obtenus:
- Diamètre du fil: 0.85 mm
- Diamètre du diaphragme: 1.4 mm
- Vitesse de pompage pour étages 1-2 et 4: 11cfm.
- Vitesse de pompage pour étage 3: aprox. 50 l/sec.

ESSAIS 1 (suite)

D'après les résultats obtenus au tableau précédent nous concluons donc qu'il est possible de garder la pompe à diffusion en état de fonctionnement même s'il n'y a pas de fil qui traverse les diaphragmes.
Comme nous l'avons plutôt mentionner la pression varie en fonction du positionnement du fil par rapport qu centre du diaphragme. Il serait donc intéressant de voir l'effet du déroulement du fil par rapport à la variation de pression dans les différents étages.
Les résultats obtenus et tabulés ci-bas sont valables pour les paramètres qui ont servis au tableau précédent.

| ETAGES | PRESSION (torr) | | | |
|---|---|---|---|---|
| | avec fil | sans fil | déroulement | |
| | | | maximum | minimum |
| 1 | 8 | 25 | 13 | 5 |
| 2 | .05 | 1 | .085 | .045 |
| 3 | $7.1 \cdot 10^{-5}$ | .030 | $9.1 \cdot 10^{-5}$ | $7.3 \cdot 10^{-5}$ |
| 4 | .05 | 1 | .085 | .045 |

ESSAIS 2.

Les résultats obtenus par l'essais 1 nous semblent parfaitement acceptables pour une aplication industrielle d'un tel procédé. Par contre de meilleur pression dans les différents étages assureraient une durée de vie supérieur aux pompes mécaniques et une meilleur protection à la pompe à diffusion.
L'obtention d'une pression inférieur sera un but facile à atteindre puisque si nous diminuons l'ouverture deu diaphragme nous aurons une plus grande étanchéité entre chaque étage. Nous reprendrons donc une série de mesure avec un diaphragme de diamètre de 1.2 mm:

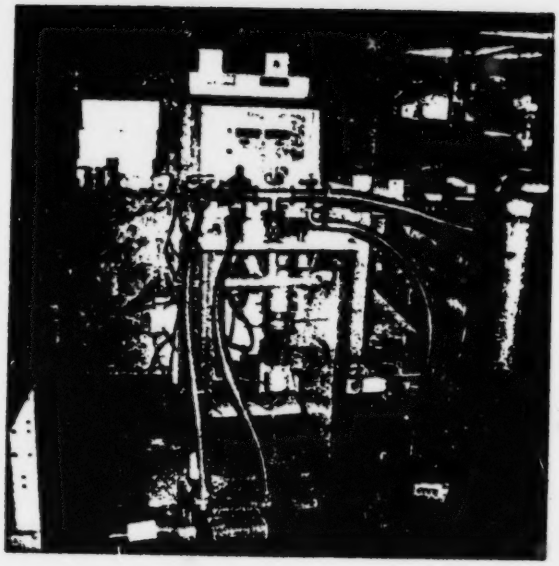
| ETAGES | PRESSION (torr) | | | |
|---|---|---|---|---|
| | avec fil | sans fil | déroulement | |
| | | | maximum | minimum |
| 1 | .640 | 18 | 2.4 | .600 |
| 2 | .023 | .85 | .03 | .02 |
| 3 | $6.0 \cdot 10^{-5}$ | .006 | $6.4 \cdot 10^{-5}$ | $5.9 \cdot 10^{-5}$ |
| 4 | .023 - | .85 | .03 | .02 |

CONCLUSION:

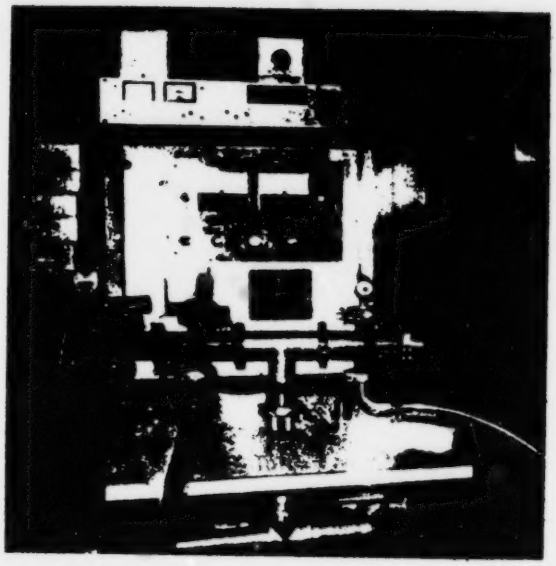
Ce projet semblent donc parfaitement réalisable sans devoir utiliser des pompes à grandes vitesses de pompage de façon à garder les coûts de ce système le plus raisonnable possible.

Il est évident qu'il est possible d'employer des pompes de 27cfm ou même plus ceci contribueraient à amiliorer les capacités du systèmes mais en contre-partie les coûts en seraient presque doublés. Puisque notre but était aussi de trouver le meilleur compromis en se basant sur les pressions obtenues et le prix de l'équippement utilisé nous conseillons donc, pour les étages de vide primaire, des pompes d'une capacité de 11cfm. à cause de leur faiencombrement et de leur prix raisonnable.

L'étage de vide secondaire offre lui aussi un grand choix de possibilités. Le groupe de pompage qui nous a servi pendant l'expérience n'était pas très rapide mais il est possible en gardant les mêmes composantes d'augmenter sa vitesse à près de 90 l/sec.. Le choix d'un groupe de pompage de ce type fut motivé par son faible coût d'achat comparativement aux pompes "ROOTS" ou aux pompes turbomoléculaires. Pour un système de production ou la chambre de procédés serait évidemment de dimensions supérieur, un groupe à diffusion semblerait toujours l'achat le plus acceptables seul sa vitesse de pompage serait le critères important.



1A



1

2

3

## APPENDIX B

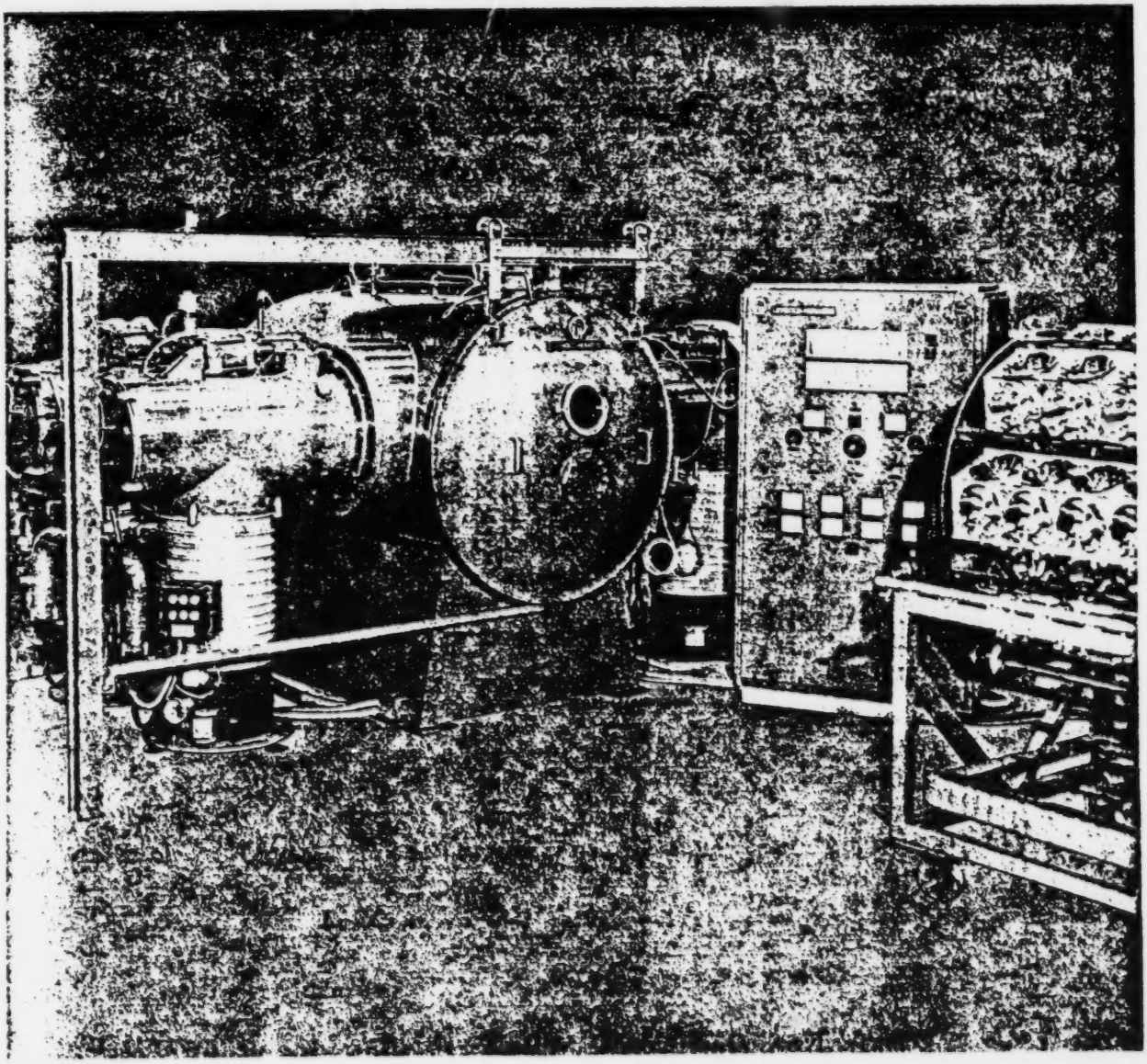

Page

- Leybold-Heraeus/metallising plants ..... 49
- High Vacuum Systems/industrial vacuum metallizers ..... 60
- Modifications of existing LH coating unit ..... 73

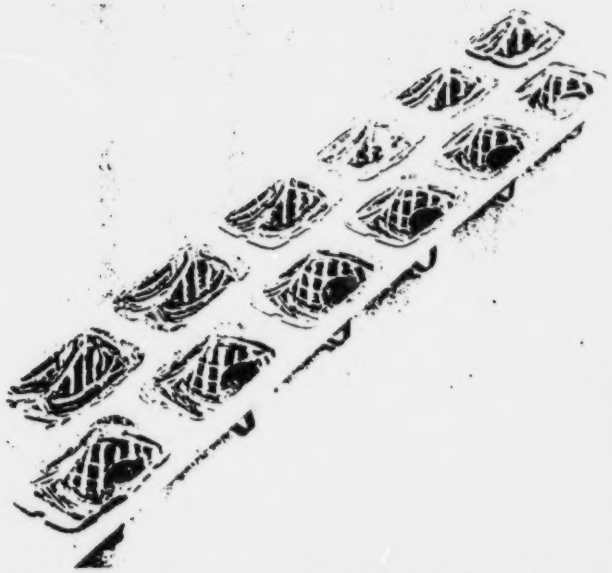
LEYBOLD-HERAEUS
49.
Vacuum Process Engineering Division

## Metallising Plants A 650 H . . . A 2500 H

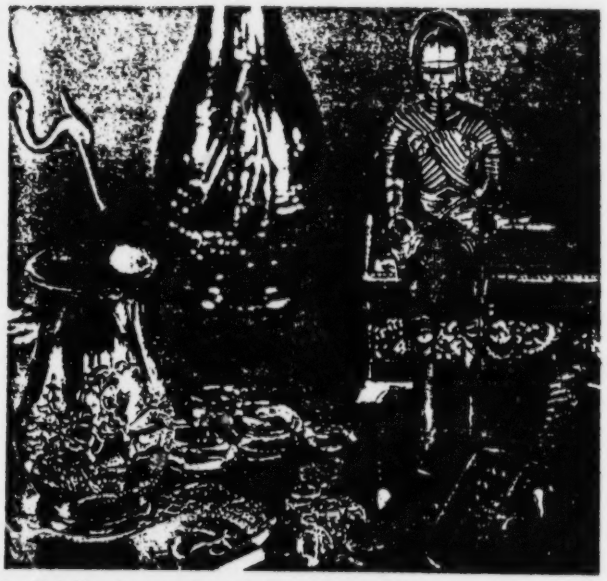
# Economical Metallising of Moulded Parts



# Contents



1 High-vacuum metallised headlamp reflectors (still in the mount)



2 Metallised souvenirs and decorative articles

## Contents


| | Page |
|---|---|
| **Applications** | 4 |
| Metals | 4 |
| Plastics | 5 |
| Glass | 5 |
| **The Process** | 5 |
| **The Design of Plants** | 6 |
| Scheme | 6 |
| Vacuum Chamber and Pumping Unit | 6 |
| The Charging System | 7 |
| Evaporation and the Vaporised Material | 8 |
| **The Process and Mode of Operation** | 8 |
| The Vapour Deposition Process | 8 |
| Operations in the Metallisation of Shapings | 9 |
| Operation and Maintenance | 10 |
| **Metallising Costs — Economy** | 10 |
| **Advantages of the Process and the Plant** | 10 |
| **Special Processes and Applications** | 10 |
| **Production Lines and Know-How** | 11 |
| **Data for Profitability Calculations** | 11 |
| **Technical Data** | 12 |

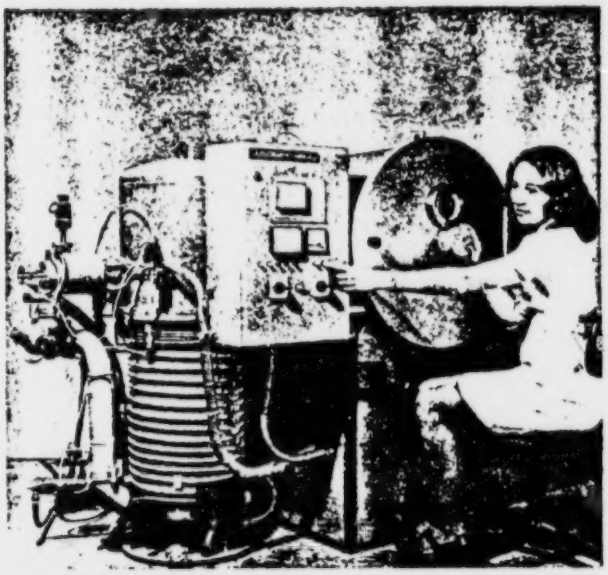
## Applications

One finds metallised mouldings almost everywhere today: such as souvenirs, fashion jewellery, toys, packaging accessories, technical goods and car accessories. In most cases, the parts have to give a shiny and decorative effect.

Economy plays a dominating role in the batch or – often enough – mass metallisation of parts.

Vapour deposition under high vacuum is not only the most modern but also the most economical metallising process. The Leybold-Heraeus plant series is designed for the economical metallising of long runs of plastic, glass and metal parts. The glossy coating may be of aluminium, copper, silver, gold and other pure metals or compounds.

Thin metal coatings are preferably applied to the following materials and products:

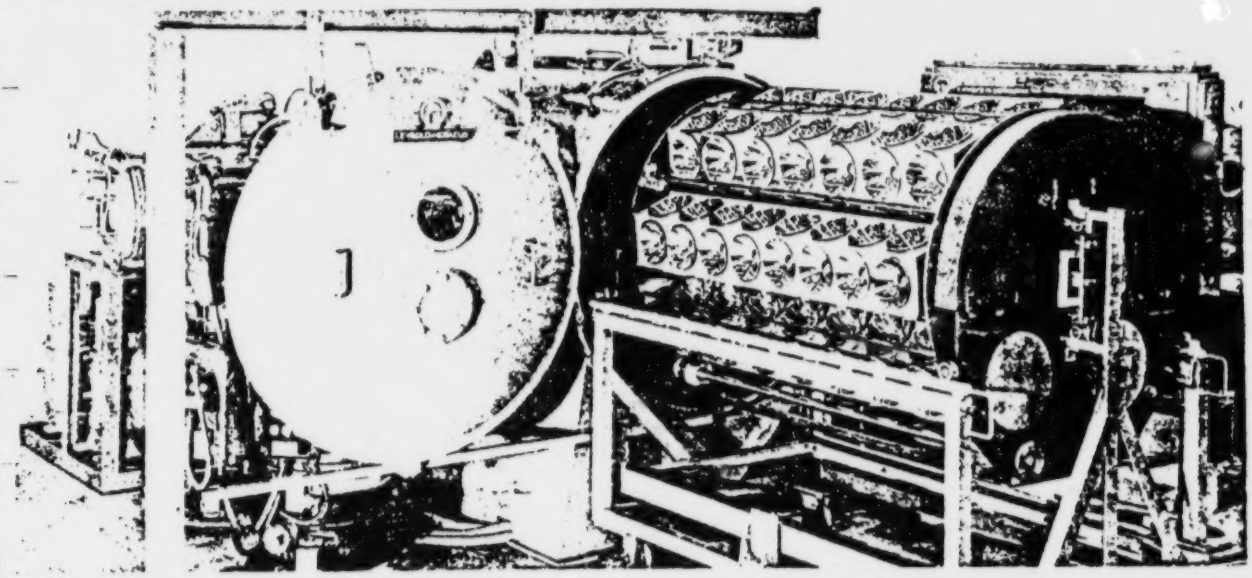


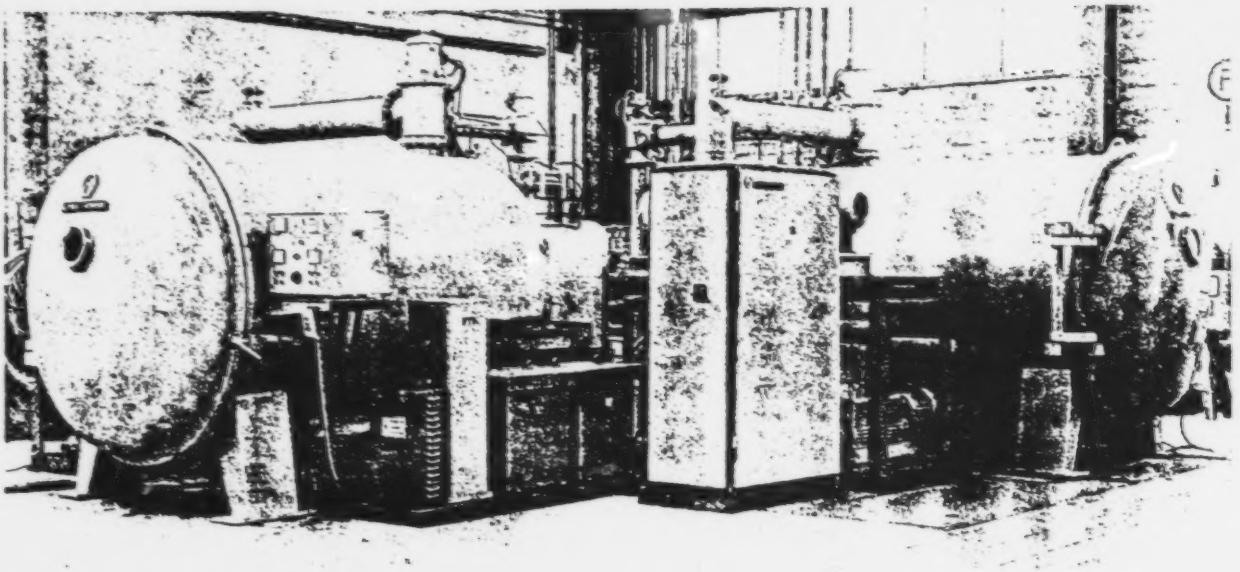
3 The A 650 H high-vacuum metallising plant – the smallest in the series

**Metals**

- Mirror coating of reflectors
- Corrosion protection through cadmium plating of bolts and other components
- Metallising of motor vehicle accessories in fittings such as trims and door handles
- Thick metallic functional coatings, for example, on circuit boards

The A 1400 H with sliding chamber door, cage containing metallised reflectors run out





5 The largest standard metallising plant, the A 2500 H

## Plastics

- Transparent parts with metallised fronts and backs
- Decoration of injection moulded and pressed parts with a combination of lacquer for coating paints and metallic layers.
- Metallisation of utility goods, car accessories, toys, musical instruments, fashionable effects and jewellery, for the furniture, clock, photographic, radio and TV industry.
- Creation of mother-of-pearl effects.
  Pre-galvanisation treatment.

## Glass

- Production of surface and reverse face mirrors.
- Mirror-metallising of rear lights and jewellery.
- Iridisation of polished and unpolished beads.

## The Process

The metallising process is based on the principle that metal vapour is evaporated and condenses on a "cold" body. If this process were to take place under atmospheric pressure, the vaporised material would oxidise immediately, and the mean free path of the metal vapour would be so short that technical utilisation would be impossible. If however the process takes place under high vacuum, one can utilise it for rational mass production. When metallising mouldings, one must also ensure that the metal vapour actually reaches all surfaces which are to be metallised. When parts are complicated, they have to be suitably rotated during the metallising process.

Metallising does not hide the surface structure of the metallised part. For this reason, rough surfaces have a dull appearance, whilst smooth surfaces have a mirror finish.

Once the necessary vacuum has been reached, metallising of many metals takes only a few seconds. The thickness of the metal coating, which is under 1 µm in practically all cases, is regulated via the length of the process and the evaporation temperature. The usual optically-dense decorative coatings are no more than 0.3 µm thick.

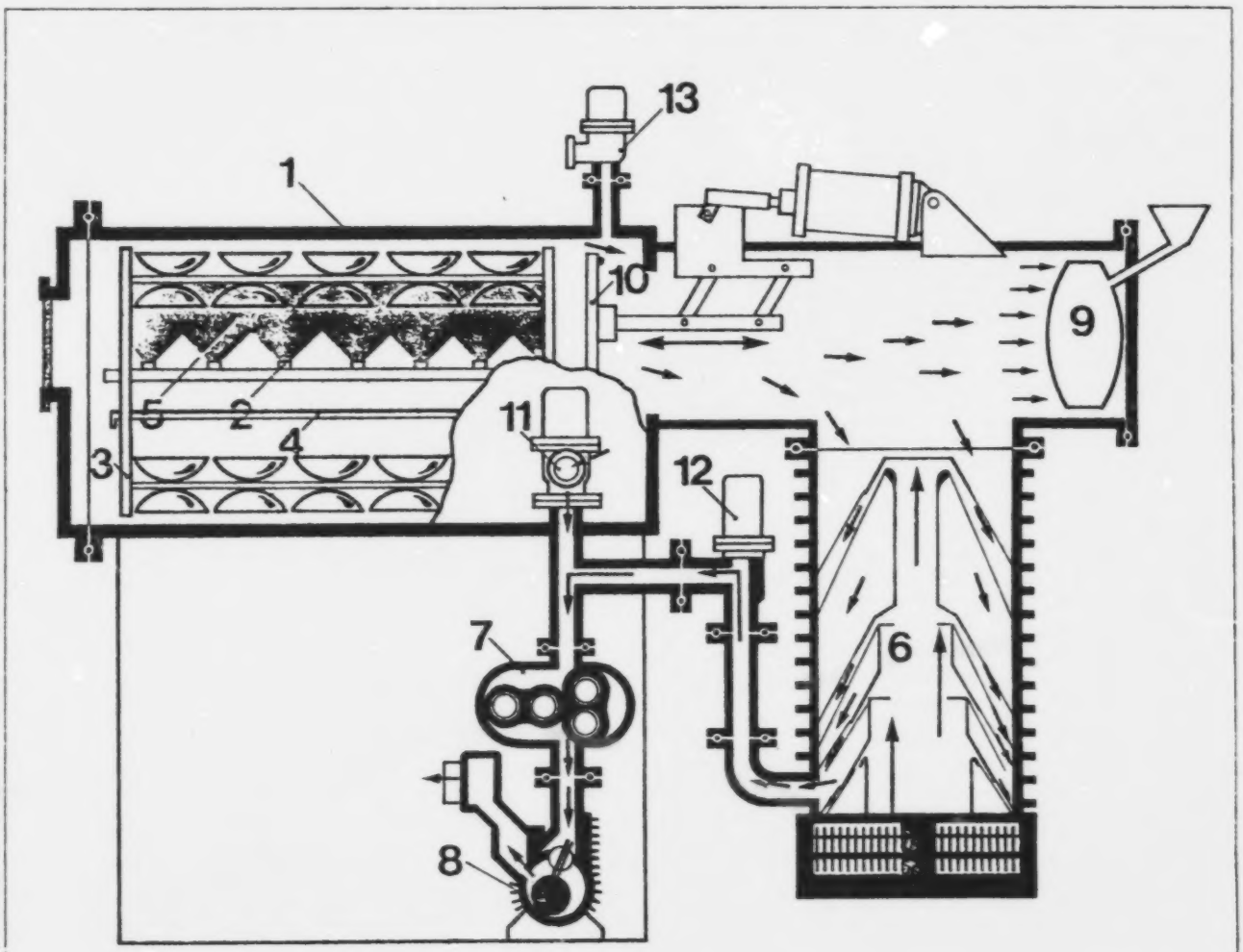
# The Design of Plants · Scheme · Vacuum Chamber and Pumping Unit

## The Design of Plants

### Vacuum Chamber and Pumping Unit

If the metallising plant is to function properly, a high operating vacuum must be achieved within the shortest possible time, and this vacuum maintained throughout the metallising process. The vacuum pumps must therefore be

6 Layout of a vapour deposition plant for metallising shapings




1 Vacuum chamber
2 Evaporator
3 Charging cage
4 Glow discharge cathode
5 Plastic parts
6 Diffusion pump
7 Roots pump
8 Rotary piston pump
9 Cryogenic trap
10 High-vacuum valve
11 Backing line valve
12 Pressure compensating valve
13 Air inlet valve

# The Design of Plants · Vacuum Chamber and Pumping Unit
# The Charging System

designed to meet the most stringent demands. This makes it possible to metallise 5–6 batches per hour when the plant is clean and the parts give off little gas.

To achieve optimal space utilisation, plants with a horizontal chamber axis are used for metallising shapings.

Fig. 6 shows the layout of a vapour deposition plant with the commonly-used high-vacuum pump set and necessary valves. The pump set consists of a rotary piston pump, a Roots pump and a diffusion pump.

The plants can also be equipped with a cryogenic trap that is either operated with liquid nitrogen or connected to a refrigeration unit. These cryogenic traps not only remove water vapour but all condensable gases and vapours that are released from the surfaces by desorption. They therefore drastically reduce the evacuation time (Fig. 7).

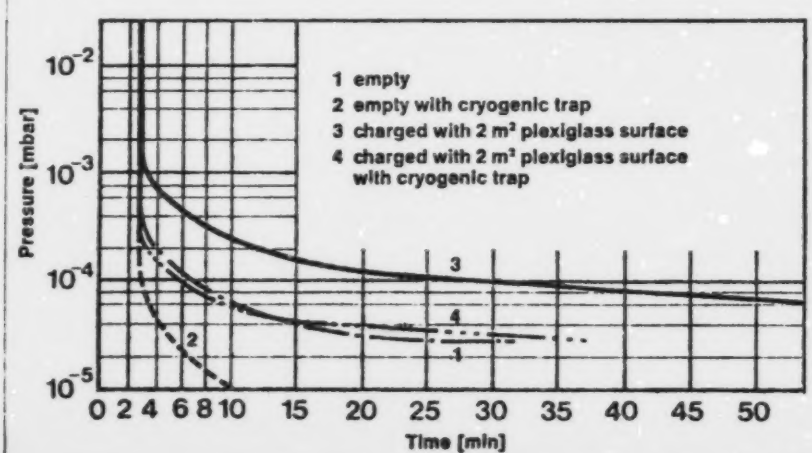
In most plants, the pumps and valves are automatically controlled, so that operating errors are excluded. Switching elements that are controlled via pressure, time or temperature ensure correct and reliable pumping. Programming of the process can be extended to the point where also vapour deposition and – if required – the glow discharge operation are also automatic. Operating personnel then have practically no influence on the results: the quality of the metallised parts is always equally high, and the reject rate is low.

## The Charging System

The second important task is carried out by the charging system. In metallising plants for shapings, the parts must be moved over the evaporator sources in a planetary orbit. Only then can one be sure of achieving even coating of stereometric articles. Even standard plants (Fig. 8) have a double rotation cage for the objects to be coated. All parts which are to be metallised are mounted in the holders. The holders may be frames, trays or rods. The charging system then moves the mouldings through the vapour zone in such a way that all surfaces are fully exposed to the vapour, whilst optimal utilisation of the evacuated chamber is achieved. The cage is run out of the plant for loading.

When the parts to be metallised are relatively flat, for example, plates or mirrors, double rotation of the parts is not necessary. In this case, the cage bearing the parts rotates only about the chamber axis, carrying the parts over the evaporator (Fig. 9).

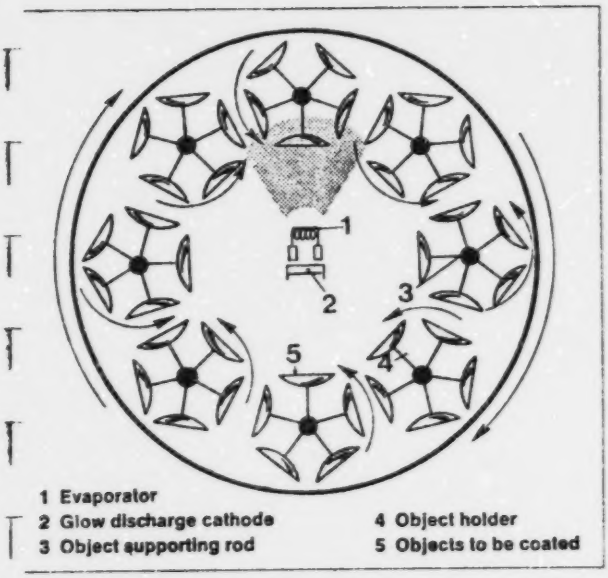
7 Pumping times of a high-vacuum metallising plant with a chamber volume of 1,100 l




**Pumping Unit**

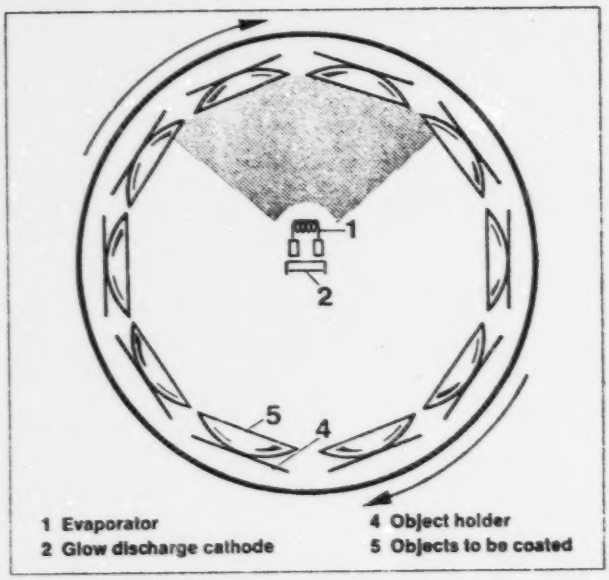
| Pumps | Pumping speed |
|---|---|
| Diffusion pump | 12 000 l · s$^{-1}$ |
| Roots pump | 440 m³ · h$^{-1}$ |
| Rotary piston pump | 200 m³ · h$^{-1}$ |

# Evaporation and the Vaporised Material
## The Process and Mode of Operation · The Vapour Deposition Process




1 Evaporator
2 Glow discharge cathode
3 Object supporting rod
4 Object holder
5 Objects to be coated

Shapings in a cage with double rotation during metallising




1 Evaporator
2 Glow discharge cathode
4 Object holder
5 Objects to be coated

9 Shapings in a cage with one axis of rotation (non-rotating mounts)

### Evaporation and the Vaporised Material

The number of evaporators depends on the size of the plant and the product which is to be produced. When the parts have complicated mouldings – for example, when the inside surfaces must also be metallised – the evaporation rate must be considerably higher than when the parts have plane surfaces.

From many years of development work, we have optimised the dimensions of the boats and the distance between these from both technical and economic viewpoints. The materials for vaporisation may be in wire or strip, granulate, tablet or powder form. The necessary amount for each charge is placed in the evaporator. All normally-used materials and other accessories can be obtained from Leybold-Heraeus. Detailed information is to be found in our brochure 17-100.2 "Evaporation Materials – Evaporating Sources and Accessories".

## The Process and Mode of Operation

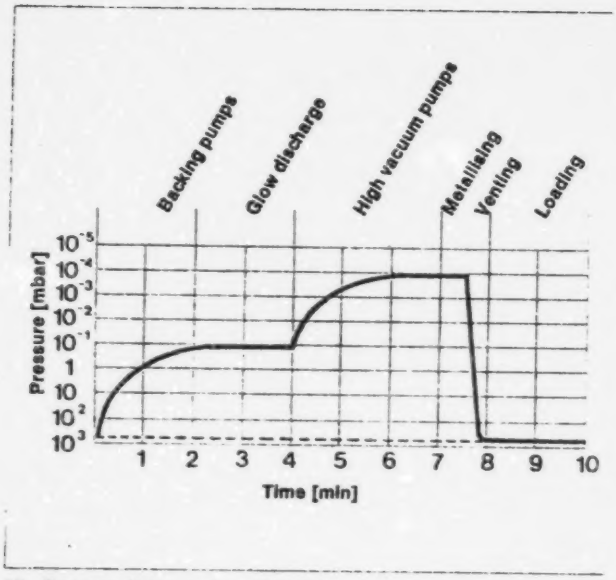
### The Vapour Deposition Process

After the necessary preliminary treatment, the parts are mounted in the cage and run into the chamber. The chamber is then evacuated.

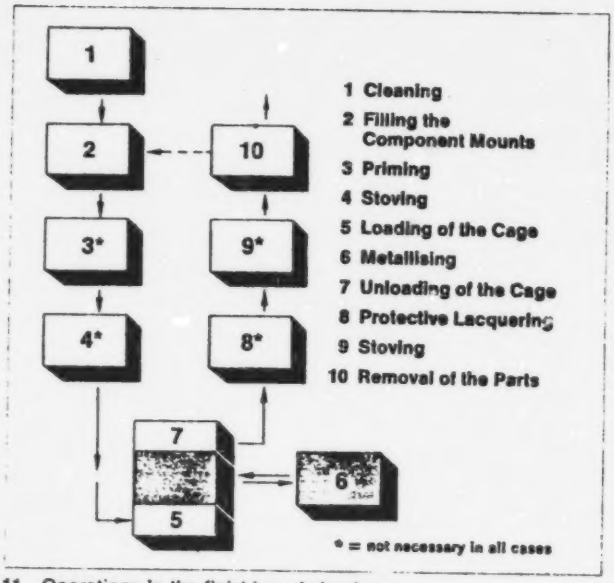
With some materials, physical cleaning is carried out and the bonding properties improved before vapour deposition by means of intensive glow discharging at approx. $10^{-1}$ mbar. Following this, evacuation of the chamber continues down to that vacuum needed for metallising. When the working vacuum has been reached, the cage begins to rotate. The thermal evaporator sources are heated to the point where the material which is to be deposited evaporates and condenses on the shapings.

This completes the metallising process; the vacuum can be broken and the cage run out of the chamber with the metallised parts. The process diagram (Fig. 10) shows the typical timing of a work cycle in a well-cleaned metallising plant.

# Operations in the Metallisation of Shapings




10 Process diagram of a work cycle




11 Operations in the finishing of shapings

## Operations in the Metallisation of Shapings

A number of operations are frequently necessary in the finishing of shapings (Fig. 11). In addition to the metallising plant, one then needs lacquering facilities and drying chambers which the parts are pre- and after-treated.The individual operations in the finishing of shapings as shown in Fig. 11 are:

**1. Cleaning**

The agent used must be suitable for the material and the type of soiling.

**2. Filling the Component Mounts**

All parts are held by component mounts. The fastenings used should be as simple as possible, as this operation is carried out by hand.

**3. Priming**

A priming lacquer is used where necessary. Depending on the shape of the parts and the quantities involved, this is either done manually, with a spray gun, or in an automatic lacquering unit.

**4. Stoving**

The lacquered parts are then stoved to harden the lacquer. The duration of this operation is specified by the lacquer manufacturer.

**5. Loading of the Cage**

After stoving, the component mounts bearing the parts are fitted to the cage of the metallising plant and pushed into the vacuum chamber.

**6. Metallising**

The chamber must first be evacuated to the necessary working vacuum before the actual metallising operation can begin.

**7. Unloading of the Cage**

When the metallising operation has been completed, the vacuum is broken, the cage is run out of the vacuum chamber and the component mounts are removed.

**8. Protective Lacquering**

If necessary, a protective lacquer is then applied to the metallised parts.

**9. Stoving**

The component mounts are then placed in a lacquer drying cabinet to harden the protective lacquer.

# Operation and Maintenance · Metallising Costs — Economy Advantages of the Process and the Plant · Special Processes and Applications

**). Removal of the Parts**

The finished parts are then removed from the component ounts and can be packed. A number of cages per metal-sing plant are adviseable, in order to be able to operate it economically. Whilst one cage is being loaded (Operation 5), a further cage is in the metallising chamber (Operation 6), hilst a third cage is being unloaded after metallising Operation 7). This avoids unnecessary waiting times.

**peration and Maintenance**

The plants are controlled from a switchboard cabinet. All umps and valves have programme control. The valves are ectropneumatically or electromagnetically actuated.

The few control switches and all monitoring elements are early arranged on the front panel of the control cabinet.

## Metallising Costs — Economy

The low metallising costs (Base of 1977) and the great eco-nomy of the plants can best be demonstrated with two amples:

**1. Screw cap**

30 mm dia.; 15 mm height; aluminium-coated

2000 caps, with 4.24 m² surface area can be metallised in one batch. With a batch time of 15 minutes, this means 8000 caps/hr. Metallising costs 2.30 DM/m² or 0.005 DM/cap (see Table 1).

**Plastic part**

110 x 80 x 5 mm; aluminium-coated on one side

540 parts with 5.8 m² surface area to be metallised make up one batch. With 15 minutes batch time, this means 2,160 units/hr. The metallising costs are then 1.68 DM/m² or approx. 0.02 DM/unit (see Table 1).

At present, there is no cheaper way of producing high-gloss metal coating on plastic.

## Advantges of the Process and the Plant

- great economy and very low metallising costs
- can be used for various materials, for example, plastics, metal, glass
- high-gloss, thin coatings of practically all pure metals and their compounds
- highly suitable for mass production methods
- even complicated shapes are satisfactorily metallised
- charging system with double rotating cage as standard
- rapid loading and unloading
- fully automatic, reliable pumping
- minimum operating and maintenance requirements
- the basic model can be sophisticated with additional components, for example, charging system
- very clean and dry process, so that no pollution control (for example, detoxification plants) measures are necessary; no safety regulation which hinder work.

## Special Processes and Applications

- compound coatings, for example, silver/gold
- iridescent coatings with a mother-of-pearl appearance
- corrosion protection for metal parts, for example, components for the aerospace industry, by metallising with cadmium or aluminium
- production of low-dazzle mirrors for the motor industry
- non-metallic protective coatings for vehicle headlight reflectors
- metallising of circuit boards for the electronics industry

# Production Lines and Know-How · Data for Profitability Calculations

## Production Lines and Know-How

Leybold-Heraeus supplies not only the individual metallising plants but also complete production plants. On request, we will also make the necessary know-how available. Depending on the terms of contract, Leybold-Heraeus activities may include the following:

1. Familiarisation courses for operating personnel of 2 – 3 days' duration in the Vacuum Process Engineering Department of the Hanau factory, free of charge
2. Provision of the necessary technical data to allow utilisation of the process
3. A written process test certificate
4. A list of all necessary evaporation materials and evaporator sources

**Table 1 Data for Profitability Calculations [1])**

| **Metallising plant for a max. surface area of 6 m²** | | |
|---|---|---|
| Purchase price | DM 100,000.00 | |
| Manpower requirements | 2 persons | |
| Power consumption | 16 kWh | |
| Water consumption | 0.7 $m^3 \cdot h^{-1}$ | |
| Evaporator requirement | 1 evaporator/hr | |
| Aluminium | 30 $g \cdot h^{-1}$ | |
| **Plant costs with 2000 operating hours/year** | DM/year | DM/hr |
| Depreciation 5 years | 20,000.00 | 10.00 |
| Interest (10 % of ½ purchase price) | 5,000.00 | 2.50 |
| Labour costs (2 x DM 20,000.00) | 40,000.00 | 20.00 |
| Power (2000 hrs x 16 kW x DM 0.10) | 3,200.00 | 1.60 |
| Water (2000 hrs x 0.7 m³ x DM 1.00) | 1,400.00 | 0.70 |
| Evaporator (2000 units/year x DM 2.80) | 5,600.00 | 2.80 |
| Aluminium (2000 hrs x 30 g x DM 17.50/kg) | 1,050.00 | 0.53 |
| Maintenance and repair (2 % of purchase price) | 2,000.00 | 1.00 |
| **Total costs** | 78,250.00 | 39.13 |

[1]) from: Stoeckhert, Klaus, "Veredeln von Kunststoff-Oberflächen", Carl-Hanser erlag, Munich and Vienna 1974

# Technical Data

**Table 2 Technical Data**

| Characteristics | Dimension | Plant Type A 650 H | A 900 H | A 1400 H | A 1900 H | A 2500 H |
|---|---|---|---|---|---|---|
| **Charge holder** | | | | | | |
| No. [2] | | 6 | 10 | 10 | 10 | 10 |
| Diameter | mm | 200 | 180 | 265 | 400 | 520 |
| Length | mm | 600 | 1 100 | 1 590 | 1 800 | 2 700 |
| Max. metallised area | $m^2$ | 2.2 | 6.2 | 12.5 | 25 | 42.5 |
| **Chamber** | | | | | | |
| Diameter | mm | 650 | 900 | 1 400 | 1 900 | 2 500 |
| Lenght (cylindrical) | mm | 800 | 1 550 | 1 850 | 2 550 | 3 400 |
| **Evaporator** | | | | | | |
| No. [3] | | 1 | 1 | 1 | 1 | 1 |
| Capacity | kVA | 4.5 | 7.5 | 20 | 40 | 60 |
| **Glow-discharge unit [4]** | | | | | | |
| Capacity | kVA | – | 2 | 2 | 4 | 4 |
| **Vacuum data** | | | | | | |
| Pumping time to $2 \times 10^{-4}$ mbar with empty, clean plant | min | 2.5 | 3.5 | 5 | 5 | 8 |
| Pumping speed | | | | | | |
| Diffusion pump | $l \cdot s^{-1}$ | 6 000 | 12,000 | 2x12,000 | 50,000 | 50,000 |
| Roots pump | $m^3 \cdot h^{-1}$ | – | 440 | 930 | 3 300 | 3 300 |
| Rotary piston pump | $m^3 \cdot h^{-1}$ | 2 x 60 | 200 | 2 x 250 | 4 x 250 | 4 x 250 |
| Cryogenic trap [4] | $l \cdot s^{-1}$ | – | 35,000 | 70,000 | 100,000 | 100,000 |
| **Electrical data** | | | | | | |
| Total approx. capacity | kVA | 20 | 38 | 85 | 150 | 184 |
| Voltage, three-phase, at 50 Hz with load-carring Mp and earthed conductor [5] | V | 380 | 380 | 380 | 380 | 380 |
| Water, pressure, min./max. | bar | 4 / 7 | 4 / 7 | 4 / 7 | 4 / 7 | 4 / 7 |
| Consumption at min. 4 bar | $l \cdot min^{-1}$ | 6 | 11 | 22 | 36.5 | 36.5 |
| Air, pressure, min./max. | bar | 6 / 8 | 6 / 8 | 6 / 8 | 6 / 8 | 6 / 8 |
| Consumption at min. 6 bar | l/Charge | 6 | 6.5 | 9 | 21 | 21 |
| **Overall dimensions** | | | | | | |
| Width | mm | 1 800 | 2 200 | 3 700 | 3 950 | 4 500 |
| Height | mm | 1 400 | 1 900 | 2 370 | 3 420 | 3 550 |
| Depth | mm | 1 650 | 2 900 | 3 750 | 4 770 | 6 500 |
| Depth with charging truck | mm | 2 500 | 4 400 | 5 750 | 7 200 | 9 700 |
| Depth of pit for DI 50,000 | mm | – | – | – | 1 400 | 1 400 |
| **Total weight** | kg | 950 | 2 500 | 5 200 | 10,800 | 13,800 |

[2]) other spacing possible on request [3]) double evaporator on request [4]) on request [5]) other connections on request

Technical alterations reserved

# INDUSTRIAL VACUUM

# METALLIZERS

DESIGNED & MANUFACTURED TO SERVE

INDUSTRY

## VACUUM METALLIZING

The use of vacuum metallizing equipment to apply thin metal coatings to a variety of products has seen rapid acceptance within industry. Wherever a glossy coating of pure metal is required, whether on plastic, metal, glass or ceramic, vacuum metallizing has been found to be both efficient and cost effective.

Common applications include:

- metallizing of automotive products, such as trim and nameplates.
- metallic coatings on circuit boards and silicon wafers.
- decorative coatings on costume jewellery, souvenirs and toys.
- corrosion protection.
- reflective coatings on mirrors.

The advantages of vacuum metallizing over other processes can be summarised in two words; economy and flexibility.

- less metal wastage.
- metallizes complicated parts.
- minimal maintenance requirements.
- suitable for coating most materials.
- minimal operational requirements.
- clean process requiring no pollution control.
- requires no special operator skills.

## The Process and Operation

Vacuum metallizing is basically a simple process where, under very low pressure, metal is evaporated by passing a high electric current through a crucible containing the metal to be vapourized. The high purity metal vapour readily adheres to the substrate material to produce the desired metallic finish. To assure the uniformity of coating, the articles to be metallized are rotated in a suitable manner by an externally driven work holder.

Operation of a vacuum metallizing plant is quite simple with many steps automated, allowing unattended operation.

- The components are loaded onto work holders. These are then fitted to a carriage which is rolled into the vacuum chamber.
- The chamber is "roughed" to a vacuum of about $10^{-1}$ torr using large positive displacement mechanical pumps.
- The high vacuum pumps are automatically valved in, bringing the chamber down to less than $10^{-4}$ torr, whereupon the metallizing begins.
- After a suitable length of time, typically several minutes as determined by the desired thickness of deposition, the chamber is automatically vented to atmosphere.
- The carriage is rolled out of the chamber and the workpieces are removed for final finishing (laquering etc.).
- For economy of operation, two or more carriages are generally used so that a loaded carriage is available once the previous batch has been completed.
- The entire operation can take as little as ten minutes.

## Production Systems

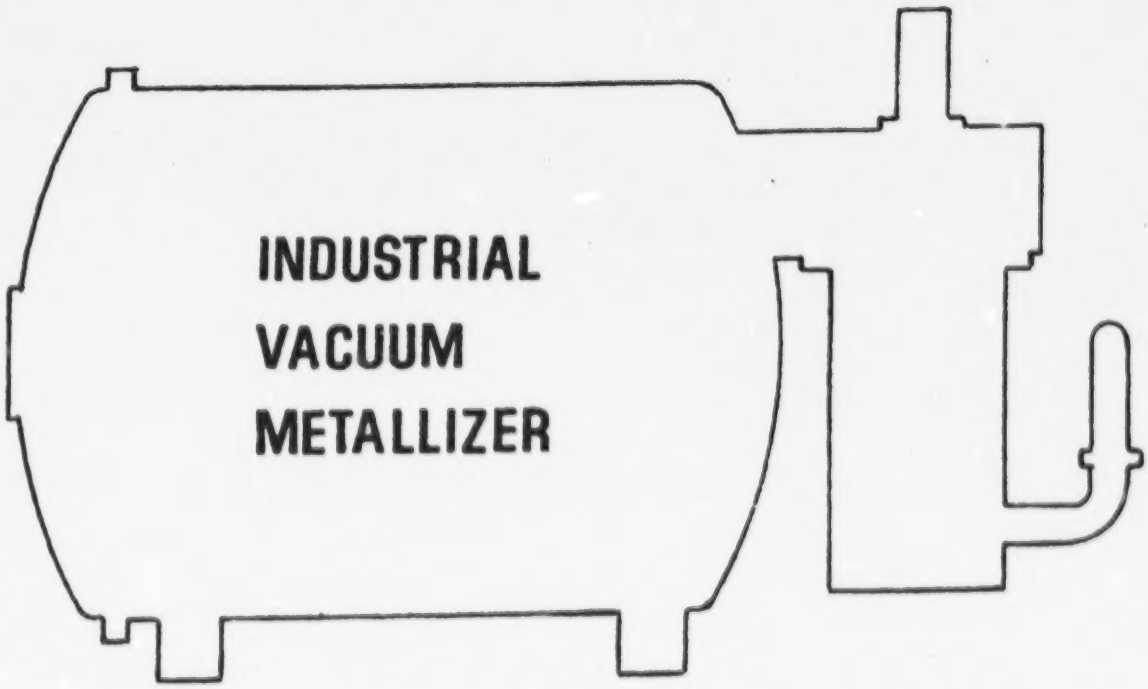
HVSI manufacturers a line of three standard metallizers which meet the requirements for a majority of applications.

Since HVSI is a custom design and manufacturing company, standard metallizer designs can be readily modified or special facilities can be designed to meet the requirements of individual customers. Special work holders and carriages can be manufactured for each application allowing the implementation of a metallizing facility tailored to suit every customer's need.

In addition to these coaters, HVSI designs and manufactures a full range of metallizing equipment for all industrial applications including roll coaters, box coaters and sputtering facilities.

For more details, call or write:

HIGH VACUUM SYSTEMS INC.
207A, Wilkinson Road,
Brampton, Ontario
L6T 4M2
Telephone: (416) 453-6632




## MODEL C48-64

HVEC metallizer designs are a culmination of over 25 years of high vacuum expertise and vacuum deposition systems development. These metallizers incorporate the most up-to-date technology emphasizing the following features:

- Rapid Pumpdown
- High Productivity
- Simplified Operation
- Operator Safety
- Low Maintenance

# SPECIFICATIONS

## METALLIZING CHAMBER

| | |
|---|---|
| Dimensions: | 48-inch diameter x 64-inch long shell, with the dished head on one end flanged and hinged to provide full opening door. |
| Material: | Mild steel with sand blasted interior and white epoxy exterior. |
| Sight Port: | 5-inch clear diameter pyrex port located in the door. |
| Feedthrus: | Rotary mechanical, for parts rack drive.<br>Electrical, for filament power.<br>Gauge couplings, for thermocouple and ionization gauges. |

Floor supports, door safety latch and internal dolly tracks are also included.

## VACUUM PUMPING SYSTEM

| | |
|---|---|
| High Vacuum Pump: | HS-16, 4 stage fractionating oil diffusion pump, with a pumping speed of 10,000 liters/second. |
| Roughing Pump: | 300 cfm two-stage mechanical pump with a dry first stage. Both stages operate from atmosphere to $10^{-1}$ torr. |
| Holding Pump: | 5.6 cfm, two stage rotary gas ballast mechanical pump. |

## VACUUM VALVES & MANIFOLDS

| | |
|---|---|
| High Vacuum Valve: | 16-inch poppet valve, pneumatically operated. |
| Roughing Valve: | 4-inch gate valve, pneumatically operated. |
| Foreline Valve: | 4-inch gate valve, pneumatically operated. |
| Holding Valve: | 1-inch angle valve pneumatically operated. |
| Air-Release Valve: | 1-inch angle valve pneumatically operated, located in high vacuum valve body. |
| Manifold Air-Release: | Two 1/4-inch angle valves, solenoid operated from pump ON-OFF switches. |

## VACUUM GAUGES

| | |
|---|---|
| Thermocouple Gauge: | Two, one located in foreline and one in the roughing line. |
| Ionization Gauge: | G-79-IT, hot cathode type located in the high vacuum manifold. |

## CONTROL CONSOLE

| | |
|---|---|
| Console: | NEMA 1 floor mounted panel enclosure and power panel. |
| Gauge Control: | TC/Ion combination controller. |
| Vacuum Control Panel: | Vacuum graphic panel with lighted pushbutton stations for:<br>a) control power<br>b) roughing pump<br>c) diffusion pump<br>d) roughing valve<br>e) foreline valve<br>f) air release valve<br>g) high vacuum valve<br>h) holding pump |
| Rotary Drive Panel: | Parts carriage variable speed drive control with "ON-OFF" switch. |
| Filament Control: | Variable reactance transformer 20KVA, with controls to provide filament power. |

Components are interlocked for proper sequence and wired for failsafe operations.

Model C48-64

## INTERIOR MECHANISMS

**Parts Carriage:** Two 6-station rotary carriage and support dollies are supplied complete with bus bars, filament holders and drive mechanism.

**Electrical Contactor:** 2,000 ampere, spring loaded, contactor supplies power to the internal bus bars when the carriage is locked in place.

## UTILITIES REQUIRED

a. Electrical Power

| | | |
|---|---|---|
| 1. | Diffusion pump | 10 KW |
| 2. | Mechanical pump | 12 HP |
| 3. | Control panel | 3 KW |
| 4. | Holding pump | 1/2 HP |
| 5. | Filament power supply | 20KW, peak |

b. Water — 70°F approximate

| | | |
|---|---|---|
| 1. | Diffusion pump | 1 GPM |
| 2. | Mechanical pump | 1 GPM |

c. Air — Clean, dry, 80 psig nominal

## OPTIONS

a. Arrangements of pumping equipment, door opening and operation side.

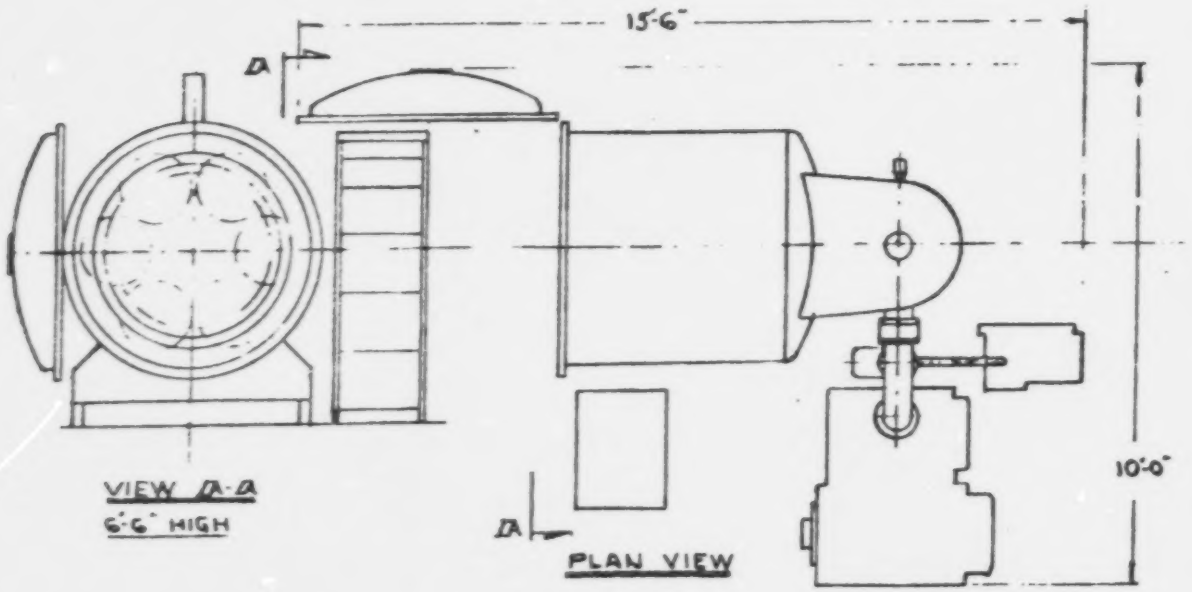
b. An automatic system cycle control from "start" to "air-release".

c. Planetary type interior mechanism, for better coverage and more uniform coating.

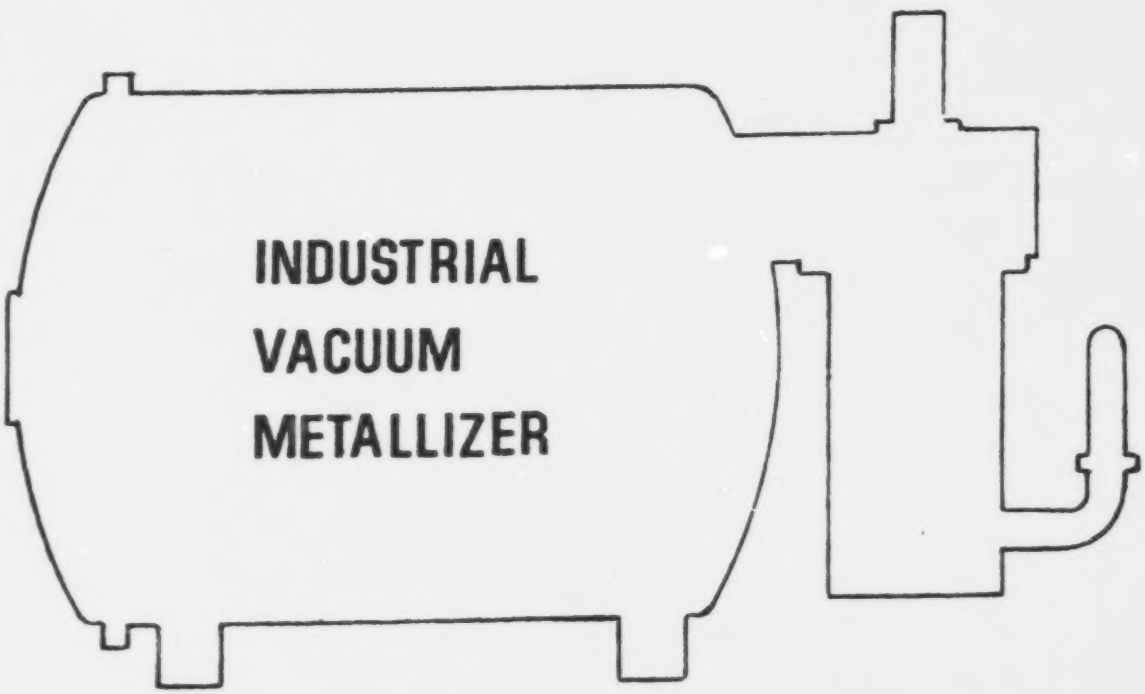
d. Extra carriages and dollies.

e. Stainless steel liners.

f. Variable station parts carriage.




HIGH VACUUM SYSTEMS INC.
207A Wilkinson Road,
Brampton, Ontario, Canada.
L6T 4M2.
(416) 453-6632



# INDUSTRIAL VACUUM METALLIZER

## MODEL C66-72

HVEC metallizer designs are a culmination of over 25 years of high vacuum expertise and vacuum deposition systems development. These metallizers incorporate the most up-to-date technology emphasizing the following features:

- Rapid Pumpdown
- High Productivity
- Simplified Operation
- Operator Safety
- Low Maintenance

# SPECIFICATIONS

## METALLIZING CHAMBER

| | |
|---|---|
| Dimensions: | 66-inch diameter x 72-inch long shell, with the dished head on one end flanged and hinged to provide full opening door. |
| Material: | Mild steel with sand blasted interior and white epoxy exterior. |
| Sight Port: | 5-inch clear diameter pyrex port located in the door. |
| Feedthrus: | Rotary mechanical, for parts rack drive.<br>Electrical, for filament power.<br>Gauge couplings, for thermocouple and ionization gauges. |

Floor supports, door safety latch and internal dolly tracks are also included.

## VACUUM PUMPING SYSTEM

| | |
|---|---|
| High Vacuum Pump: | HS-20, 4 stage fractionating oil diffusion pump, with a pumping speed of 18,000 liters/second. |
| Roughing Pump: | 600 cfm two-stage mechanical pump with a dry first stage. Both stages operate from atmosphere to $10^{-1}$ torr. |
| Holding Pump: | 5.6 cfm, two stage rotary gas ballast mechanical pump. |

## VACUUM VALVES & MANIFOLDS

| | |
|---|---|
| High Vacuum Valve: | 20-inch poppet valve, pneumatically operated. |
| Roughing Valve: | 4-inch gate valve, pneumatically operated. |
| Foreline Valve: | 4-inch gate valve, pneumatically operated. |
| Holding Valve: | 1-inch angle valve pneumatically operated. |
| Air-Release Valve: | 1-inch angle valve pneumatically operated, located in high vacuum valve body. |
| Manifold Air-Release: | Two 1/4-inch angle valves, solenoid operated from pump ON-OFF switches. |

## VACUUM GAUGES

| | |
|---|---|
| Thermocouple Gauge: | Two, one located in foreline and one in the roughing line. |
| Ionization Gauge: | G-79-IT, hot cathode type located in the high vacuum manifold. |

## CONTROL CONSOLE

| | |
|---|---|
| Console: | NEMA 1 floor mounted panel enclosure and power panel. |
| Gauge Control: | TC/Ion combination controller. |
| Vacuum Control Panel: | Vacuum graphic panel with lighted pushbutton stations for: |

a) control power
b) roughing pump
c) diffusion pump
d) roughing valve
e) foreline valve
f) air release valve
g) high vacuum valve
h) holding pump

| | |
|---|---|
| Rotary Drive Panel: | Parts carriage variable speed drive control with "ON-OFF" switch. |
| Filament Control: | Variable reactance transformer 25KVA, with controls to provide filament power. |

Components are interlocked for proper sequence and wired for failsafe operations.

## INTERIOR MECHANISMS

**Parts Carriage:** Two 6-station rotary carriage and support dollies are supplied complete with bus bars, filament holders and drive mechanism.

**Electrical Contactor:** 2,500 ampere, spring loaded, contactor supplies power to the internal bus bars when the carriage is locked in place.

## UTILITIES REQUIRED

a. Electrical Power

| | | |
|---|---|---|
| 1. | Diffusion pump | 15 KW |
| 2. | Mechanical pump | 20 HP |
| 3. | Control panel | 3 KW |
| 4. | Holding pump | 1/2 HP |
| 5. | Filament power supply | 25 KW, peak |

b. Water — 70°F approximate

| | | |
|---|---|---|
| 1. | Diffusion pump | 1-1/2 GPM |
| 2. | Mechanical pump | 3 GPM |

c. Air — Clean, dry, 80 psig nominal

## OPTIONS

a. Arrangements of pumping equipment, door opening and operation side.

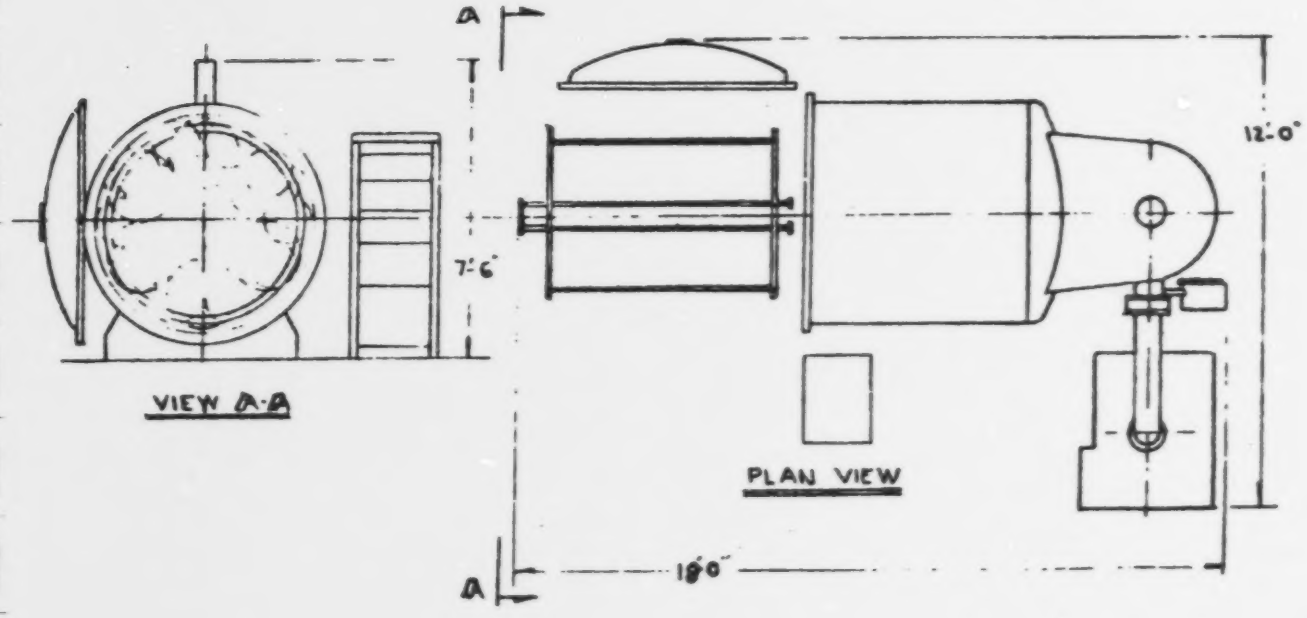
b. An automatic system cycle control from "start" to "air-release".

c. Planetary type interior mechanism, for better coverage and more uniform coating.

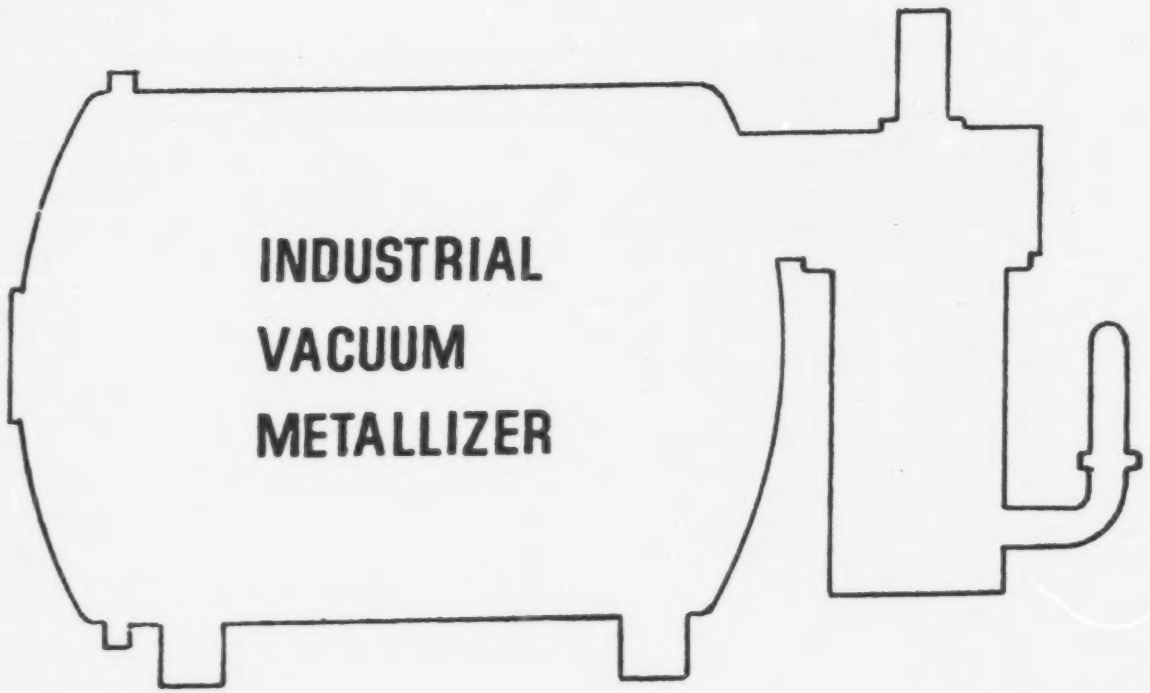
d. Extra carriages and dollies.

e. Stainless steel liners.

f. Variable station parts carriage.




HIGH VACUUM SYSTEMS INC.
207A Wilkinson Road,
Brampton, Ontario, Canada.
L6T 4M2.
(416) 453-6632



# INDUSTRIAL VACUUM METALLIZER

## MODEL C72-82

HVEC metallizer designs are a culmination of over 25 years of high vacuum expertise and vacuum deposition systems development. These metallizers incorporate the most up-to-date technology emphasizing the following features:

- Rapid Pumpdown
- High Productivity
- Simplified Operation
- Operator Safety
- Low Maintenance

# SPECIFICATIONS

## METALLIZING CHAMBER

| | |
|---|---|
| Dimensions: | 72-inch diameter x 82-inch long shell, with the dished head on one end flanged and hinged to provide full opening door. |
| Material: | Mild steel with sand blasted interior and white epoxy exterior. |
| Sight Port: | 5-inch clear diameter pyrex port located in the door. |
| Feedthrus: | Rotary mechanical, for parts rack drive.<br>Electrical, for filament power.<br>Gauge couplings, for thermocouple and ionization gauges. |

Floor supports, door safety latch and internal dolly tracks are also included.

## VACUUM PUMPING SYSTEM

| | |
|---|---|
| High Vacuum Pump: | HS-32, 4 stage fractionating oil diffusion pump, with a pumping speed of 33,000 liters/second. |
| Roughing Pump: | 600 cfm two-stage mechanical pump with a dry first stage. Both stages operate from atmosphere to $10^{-1}$ torr. |
| Holding Pump: | 15 cfm, two stage rotary gas ballast mechanical pump. |

## VACUUM VALVES & MANIFOLDS

| | |
|---|---|
| High Vacuum Valve: | 32-inch poppet valve, pneumatically operated. |
| Roughing Valve: | 6-inch gate valve, pneumatically operated. |
| Foreline Valve: | 6-inch gate valve, pneumatically operated. |
| Holding Valve: | 1-inch angle valve pneumatically operated. |
| Air-Release Valve: | 1-inch angle valve pneumatically operated, located in high vacuum valve body. |
| Manifold Air-Release: | Two 1/4-inch angle valves, solenoid operated from pump ON-OFF switches. |

## VACUUM GAUGES

| | |
|---|---|
| Thermocouple Gauge: | Two, one located in foreline and one in the roughing line. |
| Ionization Gauge: | G-79-IT, hot cathode type located in the high vacuum manifold. |

## CONTROL CONSOLE

| | |
|---|---|
| Console: | NEMA 1 floor mounted panel enclosure and power panel. |
| Gauge Control: | TC/Ion combination controller. |
| Vacuum Control Panel: | Vacuum graphic panel with lighted pushbutton stations for: |

a) control power
b) roughing pump
c) diffusion pump
d) roughing valve
e) foreline valve
f) air release valve
g) high vacuum valve
h) holding pump

| | |
|---|---|
| Rotary Drive Panel: | Parts carriage variable speed drive control with "ON-OFF" switch. |
| Filament Control: | Variable reactance transformer 30KVA, with controls to provide filament power. |

Components are interlocked for proper sequence and wired for failsafe operations.

## INTERIOR MECHANISMS

**Parts Carriage:** Two 6-station rotary carriage and support dollies are supplied complete with bus bars, filament holders and drive mechanism.

**Electrical Contactor:** 3,000 ampere, spring loaded, contactor supplies power to the internal bus bars when the carriage is locked in place.

## UTILITIES REQUIRED

a. Electrical Power

| | | |
|---|---|---|
| 1. | Diffusion pump | 24 KW |
| 2. | Mechanical pump | 20 HP |
| 3. | Control panel | 3 KW |
| 4. | Holding pump | 1 HP |
| 5. | Filament power supply | 30 KW, peak |

b. Water — 70°F approximate

| | | |
|---|---|---|
| 1. | Diffusion pump | 3 GPM |
| 2. | Mechanical pump | 3 GPM |

c. Air — Clean, dry, 80 psig nominal

## OPTIONS

a. Arrangements of pumping equipment, door opening and operation side.

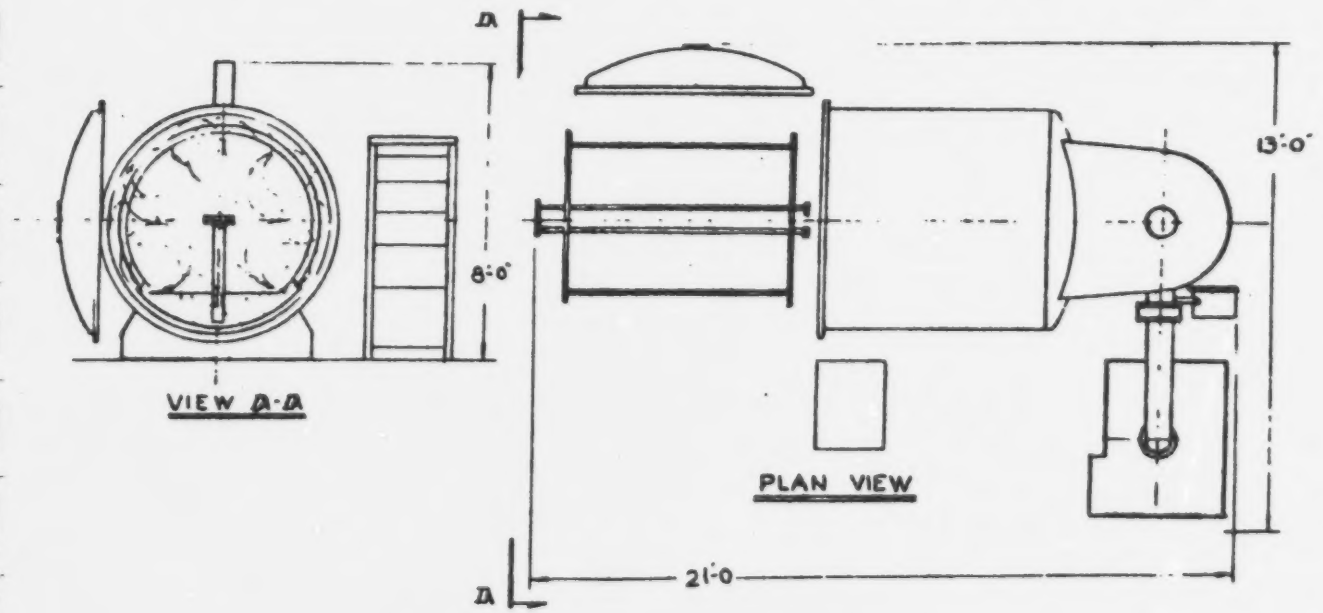
b. An automatic system cycle control from "start" to "air-release".

c. Planetary type interior mechanism, for better coverage and more uniform coating.

d. Extra carriages and dollies.

e. Stainless steel liners.

f. Variable station parts carriage.

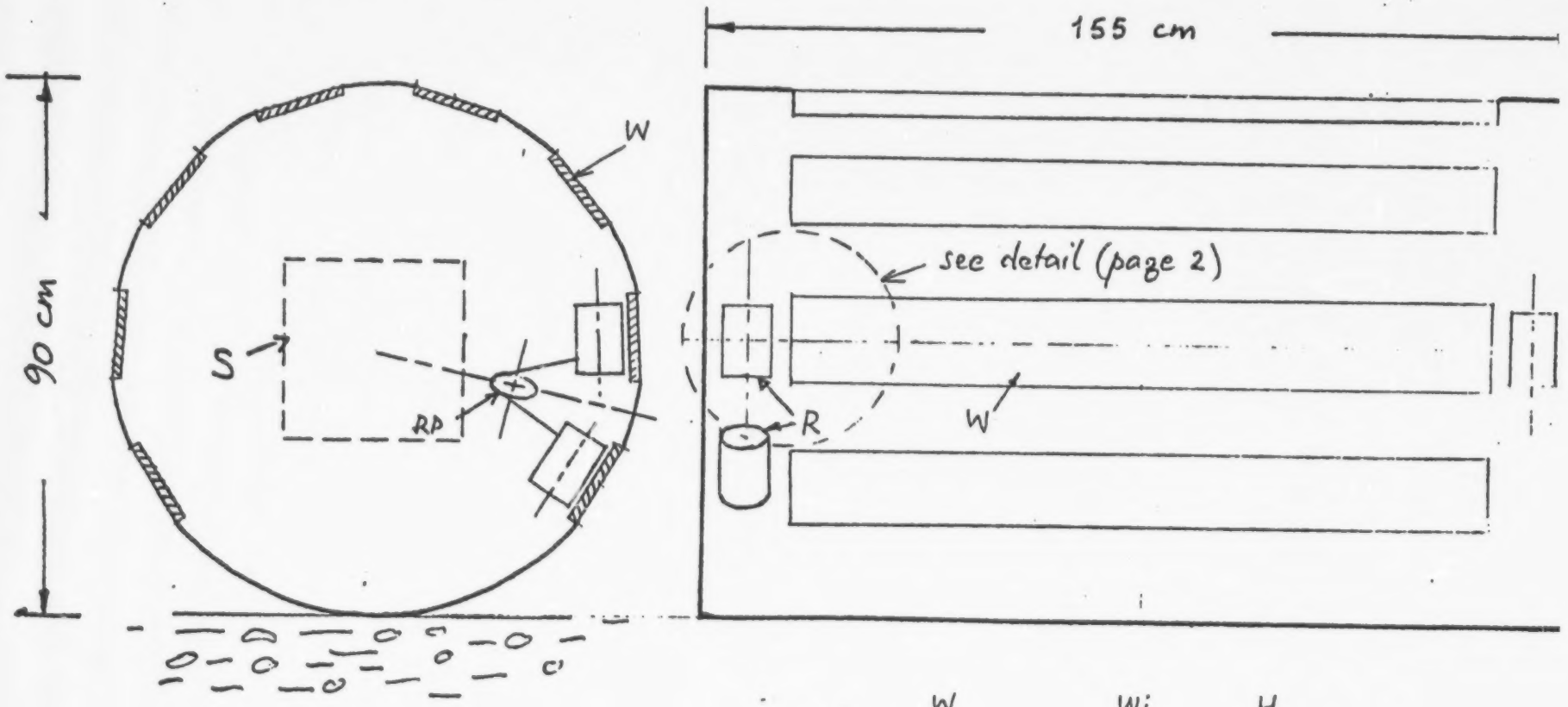



HIGH VACUUM SYSTEMS INC.
207A Wilkinson Road,
Brampton, Ontario, Canada.
L6T 4M2.
(416) 453-6632

# Pilot LMP using Leybold-Heraeus "A 900H" vacuum chamber



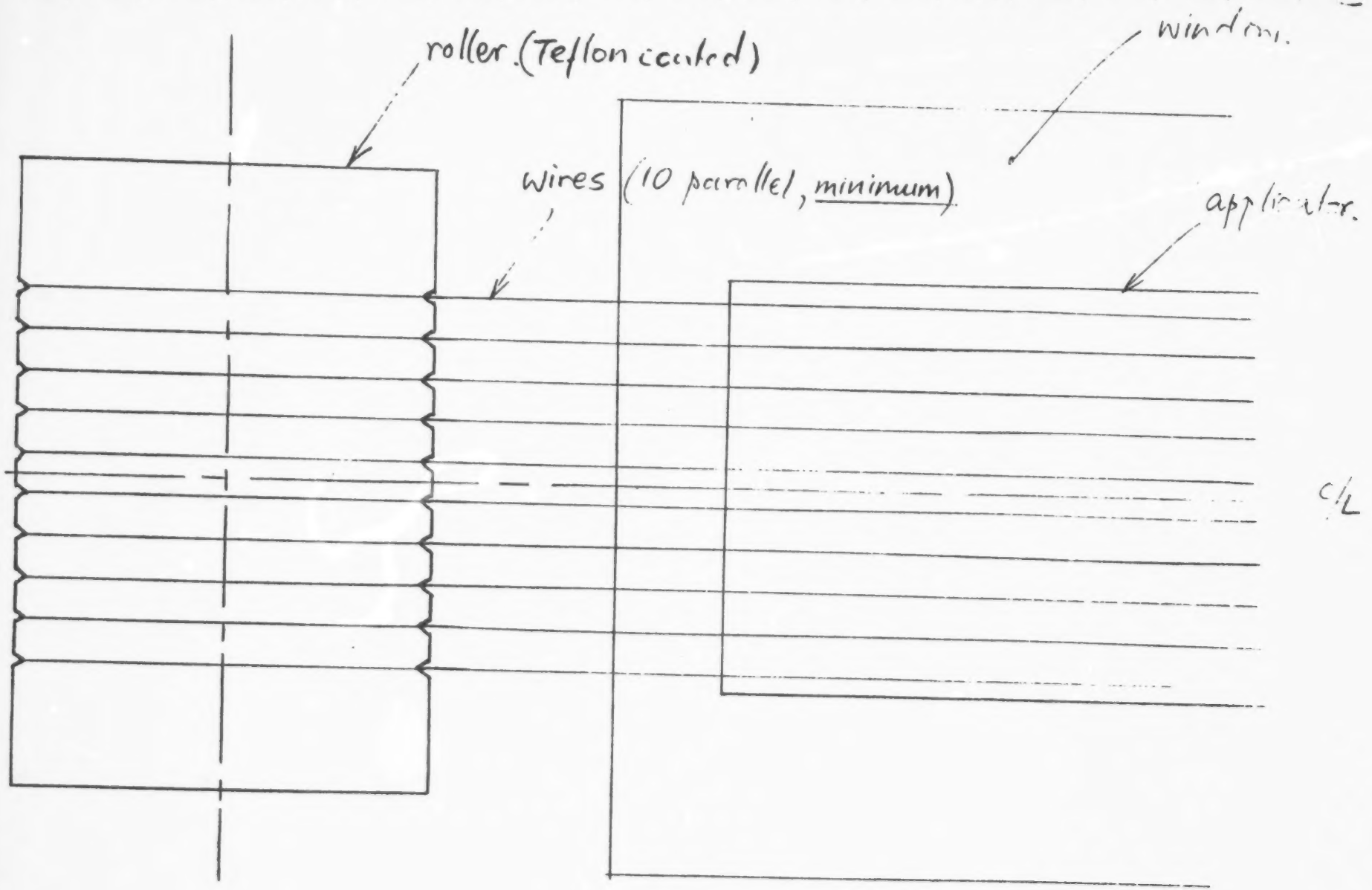
See also explanatory notes on page 4.




W = window
R = roller
Wi = wire,
H = i.r. heater/screen
RP = relay pulley
S = central space reserved for feed-, uptake reels, drive motor, etc.

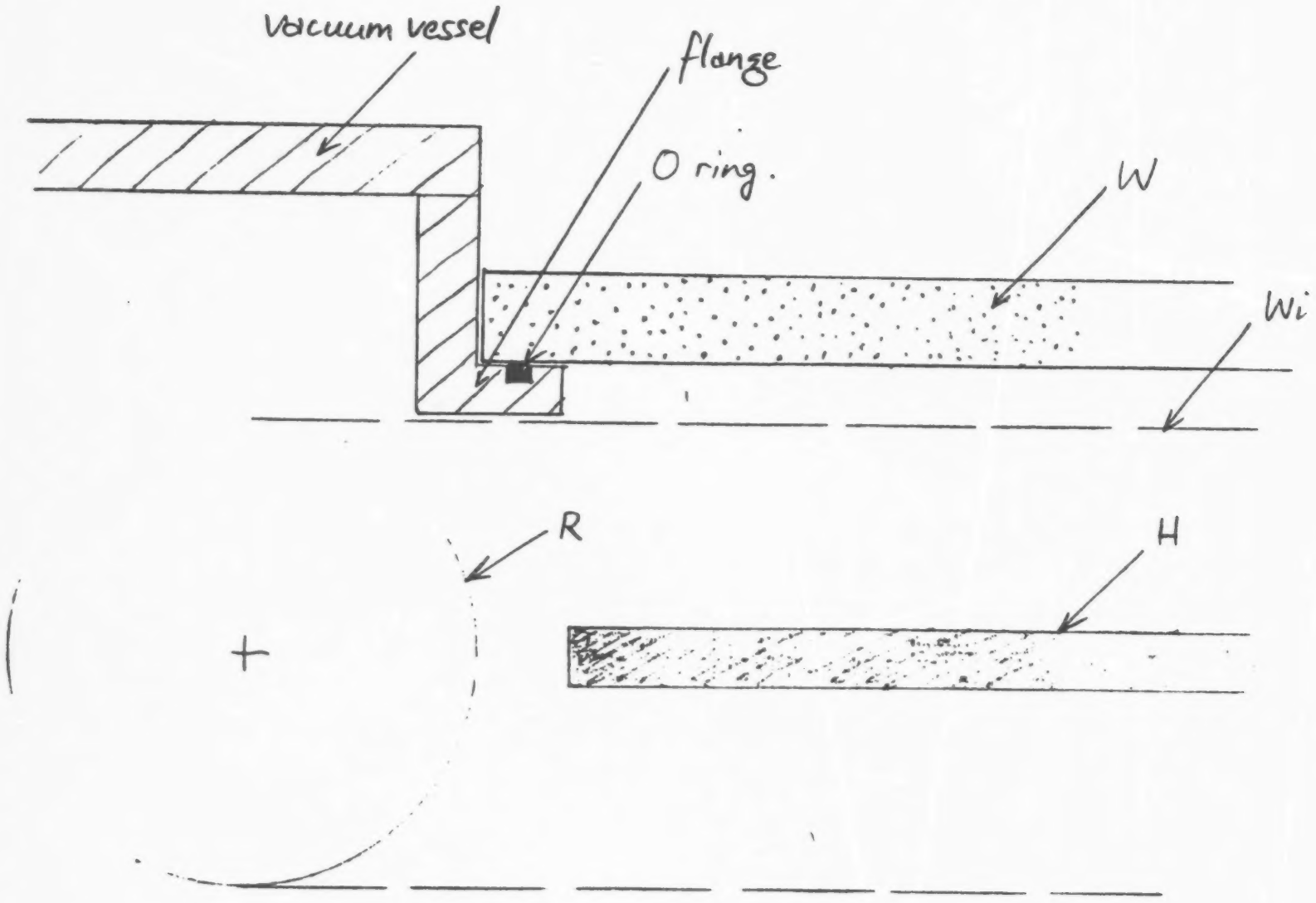
MR Westheimer 14 Nov 1981

scale: 1 : 10




MRW 14Dec81

Scale: 1 : 1




Scale : 1 : 1

MRW 14 Dec 81

## APPENDIX C

Page

Major suppliers


- Pyrometer ..... 76
- Vacuum system ..... 84
- Microwave generator ..... 91
- Infra red heating system ..... 94
- Induction heating system ..... 99

23 septembre 1981

LISTE D'ENVOI "PYROMETRES"

Conseil national de recherches Canada
National Research Council Canada

Institut de génie des matériaux
Industrial Materials Research Institute



Référence File
8210-1

September 23, 1981

Acco Industries Inc.
Division Bristol Babcock
40 Bristol Road
P.O. Box 1790
Waterbury, CT 06708
U.S.A.

Madam, Sir:

We are looking for non-contact optical (infra-red) temperature measurements between room temperature and 300°C. Our specific application is temperature measurement of a moving wire (speed up to 100 feet per minute) with a diameter of 1 millimetre (0.040") or lower. The wire moves in vacuum and the measurement is expected to be performed in air through a vacuum-tight window made of glass (or sapphire); we, therefore, look for an optical measurement device with as small as possible a target area (focusing device), with a working wave-length minimizing reading errors induced by absorption in glass and in air between window and detector; response time should be as short as possible; possibility of continuous recording would be appreciated.

We are interested in receiving information, specifications and prices and we are open to any suggestion regarding this problem.

Sincerely yours,

Dr. A. Adnot

AA/mrm

750, Bel-Air, Montréal, Québec, Canada H4C 2K3 (514) 935-8513 Telex 055-61622

Acco Industries Inc.
Division Bristol Babcock
40 Bristol Road
P.O. Box 1790
Waterbury, CT 06708
U.S.A.

Barnes Engineering Co. Stamford
30 Commerce Road
Stamford, CT 06904
U.S.A.

Bloom Eng. Co. Inc.
Horning and Curry Road
Pittsburgh, PA 15236
U.S.A.

Buehler Ltd
2120 Greenwood street
P.O. Box 1459
Evanston, IL 60204
U.S.A.

Capintec Instruments Inc.
136 Summit Ave.
Montvale, NJ 07645
U.S.A.

Davis Instr. Mfg Co. Inc.
513 E 36th street
Baltimore, MD 21218
U.S.A.

E-Square Technology
1545 Morse Ave.
Ventura, CA 93003
U.S.A.

Electro-Optical Industries Inc.
P.O. Box 3770
Santa Barbara, Ca 93105
U.S.A.

Environmental Tectonics Corp.
County Line Industrial Park
Southampton, PA 18966
U.S.A.

EPIC Inc.
150 Nassau street
New York, NY 10038
U.S.A.

Extech International Corp.
114 State street
Boston, MA 02109
U.S.A.

General Signal Corp.
P.O. Box 60
Rochester, NY 14602
U.S.A.

IRCON Inc.
7555 N. Linder Ave.
Skokie, IL 60077
U.S.A.

Land Instruments Inc.
P.O. Box 1623
Tullytown, PA 19007
U.S.A.

Leeds and Northrup Co.
Sumneytown Park
North Wales, PA 19454
U.S.A.

Mikron Instruments Co. Inc.
P.O. Box 211
Ridgewood, NJ 07451
U.S.A.

Modutec Inc.
18 Marshall street
Norwalk, CT 06854
U.S.A.

Pyrometer Instruments Co.
234 Industrial Parkway
Northvale, NJ 07647
U.S.A.

Raytek inc.
325 Middlefield Road
Mountain View, CA 94043
U.S.A.

Servo Corp. of America
111 New South Road
Hicksville, NY 11801
U.S.A.

Sigma Instruments Inc.
170 Pearl street
Braintree, MA 02184
U.S.A.

Standard Equipment Co.
9240 N. 107th street
P.O. Box 23060
Milwaukee, WI 53224
U.S.A.

Telatemp Corp.
P.O. Box 5160
Fullerton, CA 92635
U.S.A.

Transmation Inc.
977 Mount Read Blvd.
Rochester, NY 14606
U.S.A.

Vanzetti Infrared and Computer Systems Inc.
607 Neponset street
Canton, MA 02021
U.S.A.

Wahl Instruments Inc.
5720 Hannum Ave.
Culver City, CA 90230
U.S.A.

Williamson Corp.
1152 Main street
Concord, MA 01742
U.S.A.

Canadian Chromalox
243 boulard Hymus
Pointe-Claire, Québec H9R 1G3

Agatronics
41 Horner Ave, Unit 5
Toronto, Ontario M8Z 4X4

Ellis J.W. Industries
3030, de Miniac
Montréal, Québec H4S 1N5

Enercorp Instruments
100 Six Point
Box 20, Station U
Toronto, Ontario M8Z 5M4

Esprolab
121 Milvan Dr.
Weston, Ontario M9L 1Z8

Fisher Scientific
8505 Devonshire
Montreal, Québec H4P 2L4

Honeywell
6277, rue St-Jacques
Montréal, Québec H4B 1T9

Hoskin Scientific
3400, rue Losch
St-Hubert, Québec J3Y 5T6

Oxford Canada
135 Exeter Road #5c
London, Ontario N6A 4B8

Siemens Electric Ltd
7300 Trans Canada Highway
Pointe-Claire, Québec H9R 1C7

Smart Alexander D
3300 Cavendish Street
Montreal, Québec H4B 2M8

Testing Machines Int'l
6 Ronald Dr.
Montreal West, Quebec H4X 1M8

Willer Engineering
1179, boulevard Décarie
Ville St-Laurent, Québec H4L 3M8

York Instruments
1262 Don Mills Road
Don Mills, Ontario M3B 2W7

LISTE D'ENVOI "VIDE"

Conseil national de recherches Canada
National Research Council Canada

Institut de génie des matériaux
Industrial Materials Research Institute



Référence File
8210-1

September 14, 1981

Edwards High Vacuum Canada Ltd
430 South Service Road West
Oakville, Ontario L6K 2H4
Canada

Madam, Sir:

We are now at the design step of a continuous open-end machine for vacuum coating of wires and strips. We are interested in receiving informations, specifications and prices on the following products:

- general industrial vacuum equipement
- vacuum pumps (mechanical, diffusion, Roots, turbo, cryopumps)
- vacuum valves, fittings, pipes, flanges, couplings, gauges
- heating equipment for vacuum heating (RF, Joule, electron bombardment, infrared sources).

We are interested in purchasing dynamic sealing equipment (stepped vacuum locks with differential pumping) needed for continuous processing (from air to vacuum to air) of wires and strips for speeds of 100 ft/min or lower. It might be interesting for us to have a visit from one of your engineers or representatives to discuss our specific needs.

Yours truly,

Dr. A. Adnot

AA:mrm

750, Bel-Air, Montréal, Québec, Canada H4C 2K3 (514) 935 8513 Telex 055-61622

Edwards High Vacuum Canada Ltd
430 South Service Road West
Oakville, Ontario L6K 2H4
Canada

Mill Lane Engineering Co. Inc.
10 Garfield Circle
Burlington, MA 01803
U.S.A.

Thermoionics Lab. Inc.
P.O. Drawer 3711
Hayward, CA 94544
U.S.A.

Thin Film Technology
P.O. Box 1942
850 N. Mc Murray Road
Buellton, CA 93427
U.S.A.

Ultra High Vacuum Instruments Ltd.
1140 Heritage Rd
Burlington, Ontario L7L 4X9
Canada

Sargent-Welch Scientific Co-Vacuum Division
7300 N. Linder Avenue
P.O. Box 1026
Skokie, IL 60076
U.S.A.

COMPTECH
1400 Dell Avenue
Campbell, CA 95008
U.S.A.

Air Products and Chemicals Inc.
1919 Vultee Street
Allentown, PA 18103
U.S.A.

Cooke Vacuum Products
13 Merritt Street
So. Norwalk, CT 06854
U.S.A.

High Vacuum Apparadus Mfg. Co.
26545 Corporate Ave.
Hayward, CA 94545
U.S.A.

HPS Corporation
1898 S. Flatiron Ct
Boulder, CO 80301
U.S.A.

Torr Vacuum Products
7121 Hayvenhurst Ave.
Van Nuys, CA 91406
U.S.A.

T.M. Vacuum Products Inc.
630 Warrington St.
Riverton, NJ 08077
U.S.A.

ADVACO
37 New Plant Ct.
Owings Mills, MD 2117
U.S.A.

EVERY Eng. Company Inc.
714 South West Blvd
Vineland, NJ 08360
U.S.A.

ULVAC Corp.
P.O. Box 799
58 Portland Road
Kennebunk, Maine 04043
U.S.A.

AIRCO-TEMESCAL
2850 Seventh Street
Berkeley, CA 94710
U.S.A.

Vacoa
390 Central Avenue
P.O. Box 160
Bohemia, NY 11716
U.S.A

Vacuum Instruments Corp.
6 Stepar Place
Huntington Station, NY 11746
U.S.A

Vacuum Research Mfg. Co.
3100 Crow Canyon Road
San Ramon, CA 94583
U.S.A.

MDC Mfg Co.
210 Littlefield Ave.
South San Francisco, CA 94080
U.S.A.

High Vacuum Equipment Corp.
110 Industrial Park Road
Hingham, MA 02043
U.S.A.

Balzers Corp.
8 Sagamore Park Road
Hudson NH 03051
U.S.A.

23 septembre 1981

LISTE D'ENVOI "VIDE"

Suite: Compagnies contactées directement

- Canadian Vacuum Equipment (représentatn CVC, Alcatel, Granville-Philips)
  2755 de Miniac, St. Laurent. Tel: 337-0133
  Liaison: Mr. G. Levesque

- Radionics (représentant VEECO)
  195 Graveline, St. Laurent. Tel: 335-0105
  Liaison: Mlle. Judy McNamara

- Leyhold Heroeus Canada
  2300 Finch Avenue, W. Unit 29, Weston, Ont. M9M 2Y3
  Tel: 416-746-0050
  Liaison: Mr. J.L. Levine

- Varian Canada Inc.
  1355 Carling Avenue
  Ottawa, Ontario. K1Z 8N8 Tel: 613-728-4643
  Liaison: Mr. G. Carrea

- Tasman Scientific Inc. (Représentant CTI)
  1744 Meyerside Dr. suite 2, Mississauga, Ont. L5T 1A3 TEL: 416-677-8512
  Liaison: Mr. P.M. Hauser

23 septembre 1981

LISTE D'ENVOI"GENERATEUR ET
EQUIPEMENT MICRO-ONDES"

CENTRE
QUÉBÉCOIS
D'INNOVATION
INDUSTRIELLE

Montreal, September 16, 1981

QUEBEC INDUSTRIAL ELECTRIC INC.
2620 Paulus
Montréal (Québec)
H4S 1G1

To whom it may concern,

We are presently at the design step of a vacuum coating machine for wich we will have to buy different kinds of equipments; one of them is a microwave power generator.

The generator should meet the following specifications:

OUTPUT

- power level: variable up to 2.5 KW
- frequency: 2450 50 MHz
- regulation: ± 10% power variation for a ± 5% line voltage change
- generator: magnetron type
- reflected power: 400 W max. permitted to be returned to power source

INPUT & CONTROLS

- 208-240 VAC, 3 wires, single phase, 25A
- coolant: ± ½ gpm of $H_2O$ min.
- weight: less than 200 lbs
- control: variable power controller to be situated at distances of up to 30 feet from microwave power generator

We are interested in receiving information, specifications and prices (for 4 units) as soon as pssible. Thank you for your cooperation.

Yours truly,

Georges Archambault

Georges Archambault
Venture Analyst

GA/lb

## MICROWAVE GENERATOR

RCA LTD
21001 Autoroute Trans-Canada
Ste-Anne-de-Bellevue (Québec)
H9X 3L3

MICROWAVE INSTRUMENTS & COMPONENTS
6600 Bombardier
St-Léonard (Québec)
H1P 1E4

ACA ELECTRONIC CENTER
7018 Côte de Liesse
Montréal (Québec)
H4T 1E7

VARIAN ASSOCIATES OF CANADA LTD
434-A Isabey
St-Laurent (Québec)
H4T 1V3

RAYTHEON CANADA LTD
3016 De Miniac
Montréal (Québec)
H4S 1N5

WESBTER INSTRUMENTS LTD
750 Laurentien
St-Laurent (Québec)
H4M 2M4

MITEC MFG LTD
896 Montée de Liesse
Montréal (Québec)
H4T 1N8

QUEBEC INDUSTRIAL ELECTRIC INC.
2620 Paulus
Montréal (Québec)
H4S 1G1

HEWLETT PACKARD (CANADA) LTD
275 Hymus
Pointe-Claire (Québec)
H9R 1G7

PHILIPS ELECTRONIQUE LTD
5930 Côte de Liesse
Mont-Royal (Québec)
H4T 1E1

COMPAGNIE MARCONI CANADA
2442 Trenton
Montréal (Québec)
H3P 1Y9

COM DEV LTD
582 rue Orly
Dorval (Québec)
H9P 1E9

FARINON RS SYSTEMS
1710 Auto. Trans-Canada
Dorval (Québec)
H7P 1H7

23 septembre 1981

LISTE D'ENVOI "CHAUFFAGE INFRA-ROUGE"

Conseil national de recherches Canada
National Research Council Canada

Institut de génie des matériaux
Industrial Materials Research Institute



Référence File
8210-1

September 18, 1981

Advanced Combustion Inc.
P.O. Box 36
Don Mills, Ontario M3C 3G5

Madam, Sir:

We are interested in electrical infra-red heaters and we would like to receive a catalogue or specification sheets of your products, as well as a price list.

Yours truly,

Dr. Alain Adnot

AA:mrm

750, Bel-Air, Montréal, Québec, Canada H4C 2K3 (514) 935-8513 Telex: 055-61622

Advanced Combustion Inc.
P.O. Box 36
Don Mills, Ontario M3C 3G5

APEX Process Systems Ltd
1720 Meyerside
Mississauga, Ontario L5T 1A3

Brant Radiant Heaters Ltd
P.O. Box 373
Brantford, Ontario N3T 5N3

Caloritech Inc.
5773, rue Ferrier
Montréal, Québec H4P 1N3

Canadian Chromalox Co.
210 Rexdale Blvd
Rexdale, Ontario M9W 1R4

Canadian General Electric Co. Ltd
24 Ward street
Toronto, Ontario M6H 4A6

CAN-ENG Mfg Ltd
6800 Montrose Road
Niagara Falls, Ontario L2E 6V5

COOPER HEAT of CANADA Ltd
2746 Slough street
Mississauga (Malton)
Ontario (A) L4T 1G3

HCP Industrial Sales Ltd
P.O. Box 12
Pointe-Claire, Quebec H9R 4N5

Eclipse Fuel Engineering Co. of Canada Ltd
20 Upjohn Road
Don Mills, Ontario M3B 2V9

Electrohome Ltd
809 Wellington North
Kitchener, Ontario N2H 5L6

HP Power Drives Ltd
1299 Island street
Montreal west, Quebec H3K 2N4

Hamilton Porcelains Ltd
25 Campbell
Brantford, Ontario N3T 5N9

Hamilton Thermal Ltd
P.O. Box 3201
Station C
Hamilton, Ontario L8H 7K6

ICE Combustion Systems Inc.
6271 Dorman Road
Unit 11 and 12
Mississauga, Ontario L4V 1K6

Industrial Combustion and Equipment Ltd
525 Edouard VII
Dorval, Quebec H9P 1E7

Industrial Resistance Heating Canada Ltd
1720 Cunard
(Chomedey) Laval, Quebec H7S 2B2

NEDCO Division
Westburne Industrial Entreprise Ltd
5010 Paré street
Montreal west, Quebec H4P 1P3

Playford E. W. Ltd
5851 Upper Lachine Road
Montreal west, Quebec H4A 2B8

SCARBOROUGH and GRANT Co. Ltd
30 Lepage Court
Downsview, Ontario M3J 1Z9

SCHAVENBURG Industries Ltd
1904 Bond street
North Bay, Ontario P1B 8G8

Space-Ray Heaters Ltd
P.O. Box 9
Dehli, Ontario N4B 2W6

Tem-Pro Systems Ltd
229 Bridgeland Avenue
Toronto, Ontario M6A 1Y7

Thermal Products Ltd
210 Don Park Road
Unit 15
Markham, Ontario L3R 1C3

Thermequip Ltd
8019 rue Alfred
Montreal, Québec H1J 1J3

Westburne Industrial Entreprises Ltd
6333 Décarie Blvd
Montreal west, Quebec H3W 3E1

Wright PM Ltd
1300, boulevard Jules Poitras
Montréal, Québec H4N 1X8

Zesta Engineering Ltd
250 The Esplanada
Toronto, Ontario M5A 1J2

23 septembre 1981

LISTE D'ENVOI "CHAUFFAGE PAR INDUCTION"

Conseil national de recherches Canada
National Research Council Canada

Institut de génie des matériaux
Industrial Materials Research Institute



Référence File

8210-1

September 18, 1981

Brown Boveri Canada Ltd
Systems Division
4000 Trans-Canada Highway
Pointe-Claire, Québec H9R 1B2

Madam, Sir:

We are interested in high frequency induction heating equipment. Heating is a step in our continuous vacuum processing of copper wire; the wire with diameter 1 mm (0.040") moves at speeds up to 100 feet/minute and heating has to be performed under vacuum ($10^{-3}$ Torr or lower) up to temperatures of 300°C. We are therefore looking for HF heating equipment (power supplies, coils...) specifications and prices as well as for suggestions regarding power levels required for that application.

Yours truly,

Dr. Alain Adnot

AA:mjd

750, Bel-Air, Montreal, Québec, Canada H4C 2K3 (514) 935-8513 Telex: 055-61622

Brown Boveri Canada Ltd
Systems Division
4000 Trans-Canada Highway
Pointe-Claire, Québec H9R 1B2

Burton Industrial Electronic Services Ltd
107 Manitou Dr.
Kitchener, Ontario N2C 1L4

Can-Eng Mfg Ltd
6800 Montrose Road
Niagara Falls, Ontario L2E 6V5

F. H. Welding Machines Ltd
6701 Rexwood Road
Mississauga, Ontario L4V 1M7

LEPEL Corporation
5921 Queens Midtown Express way
Maspeth, N Y C 11378
U.S.A.

Omnitech Industrial Services Ltd
2750 Paulus
St-Laurent, Québec H4S 1G1

## APPENDIX D


Page

- Specifications of the pilot plant (letter) ..... 102
- Technical responses and quotations ..... 108

  Leybold Heraeus ..... 108

  High Vacuum Systems ..... 113

  Candadian Vacuum Equipment ..... 124

INDUSTRIAL INNOVATION CENTRE
Montréal

P.O. Box 6079, Station A, Montréal, Québec, CANADA, H3C 3A7 — Tel.: (514) 344-4647, TELEX: Bibpolytech 05-24146

January 21, 1982

Dr. Gonde Dittmer
Leybold Heraeus GMBH
D-6450 Hanau
Wilhelm-Rohn Strasse 25
Postfach 1555

Pursuant to our letter dated December 15,1981 and the telex dated December 18, 1981, we hereby send you information regarding the LMP pilot-plant we wish to acquire. In the following, general and detailed specifications are given for the system, which will hopefully permit you to prepare a cost estimate. Please also refer to the preliminary sketches transmitted before Christmas via Dr. J. Kieser.

As an introduction, let us recall briefly the nature of the project: what is needed is a pilot-unit for coating substrates by the large-volume microwave plasma (LMP) technique, the unit being based on the Leybold- Heraeus A-900-H commercial vacuum chamber. The requirements are separated in two sections, referred to as A and B, where A pertains to general specifications, and B to the substrate-geometry related specifications.

A. LMP Pilot-Plant/General Specifications

A.1 Microwave-transparent windows

- number: 8 (eight);
- length: about 1 meter;
- width: as wide as possible, between 10 and 15 cm, compatible with minimum thickness for mechanical integrity;

.../2

Established with the financial assistance of the Federal Department of Industry, Trade and Commerce and located at École Polytechnique de Montréal

- they should be as far as possible from each other, but easily accessible.

A.2 Substrate Pretreatment

- samples have to be heated to 600°C (six hundred Celsius); infra-red radiant heating is suggested, but not imposed. It is expected that heating devices will be mounted in such a way as to have eight (8) heating elements (one per window) where one heating element may comprise one or several heating tubes. Each element should be individually power-controlled.

A.3 Auxiliary access ports

- 16 auxiliary ports are needed preferably at both ends of each window, but in a region where there is no plasma;
- quote separately for 8 infra-red-transmitting viewing ports (sapphire, or high purity silica).

A.4 For purposes of rigidly fixing microwave components associated with each of the windows, we suggest at least one tapped hole ( 2cm dia.) behind each of the four corners of the windows.

A.5 Cooling

- microwave-transparent windows will probably require cooling for long deposition times, and/or continuous operation;
- for high temperature substrate operation, cooling of the vacuum vessel itself may be necessary.

A.6 Vacuum

- Base pressure in the low $10^{-3}$ Torr range or lower;
- Organic substrates will be among those placed in the vacuum chamber;
- If only mechanical pumping is used (Roots, blower and oil-sealed pump), time required to achieve low $10^{-3}$ Torr range should be indicated.

A.6 (continued)

- optional quotation required for diffusion pump with associated hardware for safe and efficient system-operation;
- vacuum gauge preferred is of the capacitance type.

A.7 Back-filling

- monomer introduction is made via eight (8) distribution devices, one for each window, connected to each other in parallel outside the vacuum chamber; each inlet tube equipped with a manually-actuated valve;
- operating pressures are expected to be lower than or equal to 10 Torr, with the most probable working pressure around 0.2 Torr;
- some means of reducing the nominal pumping speed should probably be provided in order to achieve a reasonable monomer flow, and consumption race during operation;
- options required include automatic feed gas flow and pressure regulation equipment. (electronic flowmeter and controllers preferred).

A.8 Remote-Control

- Remote control is needed for all of the most impcrtant functions: pumps, heating, motors, pressure and flow controllers; space should also be allowed for microwave controls.

B. Substrate-geometry dependent specifications

It is expected that two substrate holders will be needed, corresponding to the two general types of substrates to be coated: discrete parts, and continuous substrates (wires, strips or tapes).

B.1 Discrete parts

- relatively low priority on packing density (system is not dedicated to production);

B.1 (continued)

- high priority on versatility: very different geometries of components will be handled; typical examples are disks with diameters up to 35 cm, turbine blades, and other complex shapes such as fasteners, and so on;
- high priority on efficient and uniform heating;
- high priority on uniformity of coating, even for large substrates; as some kinds of substrates are expected to be larger than the microwave windows, a reciprocating motion of the substrate holder behind the windows seems desirable;
- substrates are to be electrically isolated from the chamber, for possible application of a bias voltage with respect to ground.

B.2 Continuous substrates

- holder and associated machinery are expected to handle:
  . copper wire AWG between 18 and 40 (corresponding diameters between 1 mm and 0.09 mm)
  . polymeric fibers
  . thin metallic or polymeric strips of widths up to 5 cm
- wire is to be arranged so that at least 10 parallel strands are associated with each window, and the first pass should be in front of one of the auxiliary ports associated with the corresponding window for pyrometric temperature measurements*;
  metallic wire is expected to be rapidly heated by direct Joule heating via two conductive pulleys, in close proximity of the feed spool;
- tension in the substrate during winding should be controlled;
- if possible, forward and backward winding would be highly desirable;
- substrate speed up to 30 meters/minute are required.

* i.r. pyrometer not to be included in this quotation

B.2 (continued)

- a low friction coefficient between samples and guiding components will probably be needed: it is suggested these components be coated with an appropriate material such as Teflon;
- metallic wire or strip may need cooling before uptake winding; please include as an option a cooling device (contact on cooled pulley or roller suggested);
- an other option is the equipment required for continuous air-to-air operation: this may include special design of main vacuum chamber, dynamic sealing equipment, additional pumping and so on.

It seems to us that all basic requirements have been summarized. The solutions to identified technical problems are only suggestions and, thus, we are open to any proposal for improvement and better efficiency. Please note that your estimate of the cost should not include any microwave components. If you need further information, please do not hesitate to contact:

Michael Wertheimer
Ecole Polytechnique de Montréal
Campus de L'Université
C.P. 6079, Succ. "A"
Montréal, Québec
H3C 3A7
(514)344-4749

or Alain Adnot
Institut de Génie des Matériaux
750 Bel-Air
Montréal, Québec
H4C 2K3
(514)935-8513

We would greatly appreciate your estimate of the cost of such a system as soon as possible to assist us in preparing a proposal for funding of the pilot facility and for the preparation of our company

.../6

business plan. It is our intention to proceed to acquisition as soon as funds are received, in approximately four months. Our complete proposal must be submitted in the next month.

Thanking you in advance for your collaboration, I am

Yours very truly,

Georges Archambault

Georges Archambault
Commercial Analyst

GA/lb

c.c.: Messrs. A. Adnot
R.A. Blais
R. Bosisio
P. Chollet
R. Hay
H. Schreiber
M. Wertheimer
M. R. Wolff

INDUSTRIAL INNOVATION
CENTRE
MONTREAL CANADA524146 BIBPOLYTEC MTL MA 11 DR.HB

RE. MR. GEORGES ARCHAMBAULT

BUDGETRAY QUOTATION NO. 013.7.1503

ON A HIGH VACUUM SYSTEM A 1000 HPP,
ESPECIALLY EQUIPPED FOR MICROWAVE PLASMAPOLYMERISATION
PROCESS

DELIVERY VOLUME:

1. HORIZONTAL VACUUM CHAMBER, 1000 MM DIAMETER,
LENGTH APPR. 1500 MM.
ONE FRONT DOOR, ONE FLANGE NW 500 AT THE REAR
AMEND WITH HIGH VACUUM VALVE AND DIFFUSION PUMP CONNECTION,
ONE FLANGE CONNECTION WITH CORNER VALVE NW 100 TO
THE ROOTS BLOWER
8 MICROWAVE WINDOWS,
OPENING: EACH APPR. 1000 MM LONG AND
90 MM WIDE, THICKNESS OF THE QUARTZ WINDOWS: 12 MM
EACH WINDOW FLANGE AREA IS WATER-COOLED.
3 RADIATION HEATERS ARE INSTALLED BETWEEN FOUR OF THE
WINDOWS.
THE REAR END CONTAINS 2 HIGH CURRENT CONTACTS AND
1 ROTARY DRIVE AXIS, TO WHICH THE SUBSTRATE CAGE IS
CONTACTED WHEN IT IS PUSHED INTO THE CHAMBER.
2. GAS INLET SYSTEM
MONOMER GAS INTRODUCTION IS MADE VIA 8 DISTRIBUTION
DEVICES , ONE FOR EACH WINDOW. EACH DEVICE CONTAINS
A MANUALLY ACTUATED CONTROL VALVE. THE MONOMER GAS
SUPPLY CONSISTS OF TWO SUPPLY CHAMBERS, ONE MIX-BOX,
VALVES AND PIPE CONNECTIONS.

3. PUMP SET AND VACUUM MEASURING INSTRUMENTS.
PUMPING IS DESIGNED FOR EITHER HIGH VACUUM OPERATION
USING THE COMPLETE PUMP/ SET, OR LOW VACUUM OPERATION USING
THE ROUGHING PUMP AND ROOTS BLOWER ONLY.
PUMP SEQUENCING IS DONE AUTOMATICALLY BY A CONTROL
UNIT.

THE PUMP SET CONSISTS OF:
1 OIL DIFFUSION PUMP DI 12000
1 HIGH VACUUM VALVE NW 500
ELECTROPNEUMATICALLY OPERATED
2 CORNER VALVES NW 100, EL-PN. OPERATED
1 CORNER VALVE NW 16 (VENTING VALVE)
1 THROTTLE VALVE BETWEEN CHAMBER AND ROOTS BLOWER
1 ROOTS BLOWER WAU 2000
1 ROTARY PISTON PUMP S 250 C (CHEMICAL VERSION)

VACUUM MEASURING INSTRUMENTS:

1 BARATRON (10 MBAR - 1 X 10MINUS 2 MBAR)
1 THERMOVAC (1000 MBAR - 1 X 10 MINUS 3 MBAR)
1 PENNINGVAC (1 X 10 MINUS 2 MBAR - 1 X 10 MINUS 6 MBAR)

4. SUBSTRATE CAGE
CONSISTING OF 10 RODS TO WHICH THE SUBSTRATES CAN BE MOUNTED, EACH 1100 MM LONG. A TURN OVER DEVICE ALLOWS TO ROTATE THE RODS ONCE PER BATCH BY 180 DEGREES. THE RODS ARE ELECTRICALLY INSULATED AGAINST GROUND. PROVISIONS ARE TAKEN, TO CONTACT THEM TO A BIAS VOLTAGE.

THE CAGE CONTAINS TWO COPPER BARS IN THE CENTRE.

IN HIGH VACUUM OPERATION

, WITH
CLAMPING DEVICES FOR TUNGSTEN FILAMENTS.

IN HIGH VACUUM OPERATION AL EVAPORATION TO THE SUBSTRATES IS ENABLED.

5. 1 TROLLEY TO MOVE THE SUBSTRATE CAGE TO AND FROM THE CHAMBER ENTRANCE.

6. CONTROLS AND POWER SUPPLIES

- PUMP SEQUENCING CONTROL

- HEATING POWER SUPPLY, THYRISTOR CONTROLLED
  MAX. POWER 4,5 KVA

- POER SUPPLY, STANDARD A 900 H FOR THERMAL EVAPORATION, CONSISTING OF
  1 HIGH CURRENT TRANSFORMER 7,5 KVA
  1 MOTOR CONTROLLED TRANSFORMER 7,5 KVA

BUDGETARY PRICE FOR THE COMPLETE EQUIPMENT

EX WORKS HANAU DM 550.000,-- (ACCURACY PLUS / MINUS 10 PERCENT)

VALIDITY OF THIS QUOTATION: 2 MONTHS
DELIVERY TIME: 8 MONTHS

YOU ALSO ASKED FOR A QUOTATION ON THE A 650 H TYPE. THIS IS NO LONGER MANUFACTURED. SPECIAL PRODUCTION WOULD REQUIRE COSTS IN THE ORDER OF THE A 1000 PHH, AS QUOTED ABOVE.

WE ARE READY TO PREPARE A DETAILED SALES CONTRACT CONSISTING OF DETAILED SPECIFICATION, LAY-OUT, ACCEPTANCE CONDITIONS AND GENERAL SALES CONDITIONS IN CASE YOU SEND US A LETTER OF INTENT.
FOR FURTHER INFORMATION DO NOT HESITATE TO CONTACT US.

REGARDS
DR. HOFMANN, MA-11

BIPPOLYTEC MTL

4184741B LHH D

Vakuumtechnik
Geräte · Bauelemente

Vakuum-
Verfahrenstechnik

Naturwissenschaftlich-
technische Lehrmittel

LEYBOLD-HERAEUS

LEYBOLD-HERAEUS GMBH

LEYBOLD-HERAEUS GMBH · Postfach 1555 · D-6450 Hanau

Industrial Innovation Centre
Attn. Mr. Georges Archambault
P.O. Box 6079
MONTREAL , Quebec H3C 3A7
CANADA

Ihr Zeichen

Ihre Nachricht vom

Tel.-Durchwahl (06181) 364- 240

Unser Zeichen
(Bitte stets angeben) MA 1 Hfm/Oe
Datum February 11, 1982

Dear Mr. Archambault,

thanks for your detailed letter, dated Jan. 21, 82.
Have now our comments to your specifications.
Generally we think it is more difficult to design the plant for wire coating than such one for coating descrete parts.
Having now obtained the exact wire dimensions from you we have not found a technical solution for the wire feeding system. The following short calculation shows the reason:
Copper, at temperatures above 200°C, has an ultimate elastic tensile strength of about 50 N/mm². That means, for a wire diameter of 1 mm Ø a maximum tension force of about F = 40 N is allowed. The system you are thinking of has one down-roll, one up-roll and between these 16 guiding rolls and at least 8 tension rolls. The total wire length for one run through the system is about 160 m, which you have to draw by a force less than 40 N , which is impossible. And with polymeric fibers and thin strips, both are not specified, we have the worst case, considering this elastomechanical problem.
Giving you and us the time to think about it, we suggest to specify the system for descrete parts first.
The following comments to your specifications therefore are related to the paragraphs A 1 to B 1 only.

Comments:

A.1.: o.k.

A.2.: The sketch in your first letter shows the substrate heating in opposite positions to the microwave windows. Heaters, designed such, that substrate temperature of 600°C will be achieved, will heat up the windows to a non-allowed value. We will think about another geometric arrangement of the heaters.

A.3.: o.k.

A.4.: o.k.

A.5.: We should devide the cooling into two parts. The first part is a watercooling of the window flanges, which will de done by Leybold-Heraeus. The second is a powerful air cooling of the windows from outside, which should be yours.

A.6.: Base pressure will be $4 \times 10^{-3}$ Torr with roots blower backed by one stage rotary piston pump. $1 \times 10^{-3}$ Torr is achievable by using a two-stage rotary piston pump.
Pump time down to the low $10^{-3}$ Torr range is about 24 minutes.

A.7.: o.k.

A.8.: o.k.

B.1.: As we do not specify the coating process we cannot guarantee coating uniformity on different shaped substrates.
To this point we expect a more detailed specification from you.
Within the given dimensions, we cannot agree on the reciprocating motion of the substrates.

As the time goes on, we expect your comments by telex, expecially to the main problem, which as I was told by Dr. Kieser could crack the whole project, if no reasonable solution can be found.

Regards

LEYBOLD-HERAEUS GmbH
Department MA 11

Hofmann

I.V. Dr. Hans Hofmann

Copy: to Mr. M. Wertheimers adress.

HIGH VACUUM SYSTEMS INC.
207A Wilkinson Road,
Brampton, Ontario, Canada.
L6T 4M2.
(416) 453-6632



Industrial Innovation Centre,
P.O. Box 6079,
Station A,
Montreal,
Quebec
H3C 3A7

April 1, 1982

Attention: Mr. George Archambault

Dear Mr. Archambault,

We have reviewed your requirement for a polymerization process coating system and as a result have formulated a conceptual system specification for the discrete parts coater. This specification, which is attached, has been used as the basis for budgetary pricing of this system.

The budgetary pricing for the discrete parts coating system is as follows:

| | |
|---|---|
| Discrete parts coating system | $200-250,000 |

To adapt this system, through special fixturing to allow limited experimentation of continuous product processing, it is estimated that an additional $40-60,000 will be required.

The additional price for the various options requested are estimated as follows:

| | |
|---|---|
| Sapphire viewports | $15,000 |
| Flow/Pressure control | $10,000 |
| Diffusion pump system | $20,000 |

The estimated delivery of this system is 26-30 weeks following approval of drawings.

In order to put these prices in perspective, the cost of a standard High Vacuum Systems Inc. C48-64 Industrial Metallizer if $160,000. This unit is comparable in size and performance to the referenced Leybold Heraeus A900H system.

Regarding the continuous product system, sufficient relatable experience for providing a budgetary estimate is extremely limited. The complexity of such a system, we would anticipate, would be far in excess of that of the discrete parts coater.

...2

Taking into account these unknowns we would estimate a price for such a system in the range of $250-350,000. Air to air handling of the product would add about another $15-20,000, other options would be as indicated for the discrete parts coater.

During the formation of this response a number of assumptions have had to be made, both in terms of the basic process, the behaviour and handability of the monomer and detailed areas of the design which could have a significant impact on the overall system design and cost. Of the two systems, the discrete parts coater probably offers the lowest technical risk. The continuous product coating system raises one major area of concern, the heating and handling of the product. The raising of product temperature to 600°C at the speed anticipated may well dictate an extremely long pre-heat section. Maintaining sufficient tension of the product during processing while ensuring that the coating is not damaged when passing over the guide pulleys would tend to indicate pulleys of large diameter and low tensions in order to minimize pulley to product surface stresses, with subsequeny complication in tension control.

A number of unknown variables, both in the design and the process itself, could have a significant impact on system design and cost. High Vacuum Systems Inc. would recommend that before proceeding to the equipment aquisition phase that a system level design study be undertaken. This study, which should be undertaken in conjunction with yourselves, would address and provide for the following:

a) Conceptual/Preliminary design of:
   (i) discrete parts coating system
   (ii) continuous product coating system
   (iii)a combination discrete/continuous coating system

b) Determination of risk areas in the design and the formulation of solutions which are compatible with process requirements.

c) Preparation of a detailed system design specification.

d) The firming up of costs and schedule.

This approach we believe, will minimize your risk on such a program and will allow the design and manufacture of a system which will meet your process development goals.

If you find this approach acceptable, High Vacuum Systems Inc., would be willing to undertake this study in conjunction with yourselves for a cost of $21,500. This study would be completed within two months.

...3

We offer vacuum technology second to none in Canada and can bring to this program the experience of thirty years in vacuum systems technology.

We look forward to being given the opportunity to work with you in the near future. If in the meantime you have any questions or we can be of further assistance please feel free to call our office.

Yours very truly,
HIGH VACUUM SYSTEMS INC.

Peter Ladd
President

Encl. - HVSI Brochure
Specification P81022
HVSI Industrial Metallizers

PL/bl

# CONCEPTUAL SPECIFICATION FOR A DISCRETE PARTS COATER UTILIZING THE POLYMERIZATION PROCESS

PREPARED FOR

INDUSTRIAL INNOVATION CENTRE

MONTREAL, QUEBEC

PREPARED BY

HIGH VACUUM SYSTEMS INC.

APRIL 1, 1982

PROPOSAL NO. P81022
ISSUE 'A'

## TABLE OF CONTENTS

1. INTRODUCTION

2. DESIGN CONSIDERATION AND CONTRAINTS

- 2.1. General
- 2.2.1. Configuration
- 2.2.2. Microwave Windows
- 2.2.3. Contaminatio
- 2.3. Pumping System
- 2.4. Fixturing and Mechanisms

3. CONCEPTUAL DESIGN CONFIGURATION - DISCRETE PART COATING SYSTEM

- 3.1. Chamber Layout
- 3.2. Vacuum Chamber
- 3.3. Pumping System
- 3.3.1. Roughing System
- 3.3.2. Diffusion Pump System
- 3.4. Discrete Parts Rack
- 3.5. Controls
- 3.6. Back Filling System

## 1. INTRODUCTION

This specification outlines a conceptual approach to the design of a system suitable for the coating of discrete parts utilizing the plasma polymerization process.

The description of the system, as outlined below, has been used to establish budgetary pricing.

## 2. DESIGN CONSIDERATION AND CONSTRAINTS

### 2.1. General

The following section reviews the areas of the LMP process which have a significant impact on the overall design philosophy with the resulting impact on system cost. Also addressed in this section, are some general areas which are applicable to the continuous product coating system.

### 2.2. Vacuum Chamber

#### 2.2.1. Configuration

Configuration of the chamber is primarily dictated by the requirement for uniform coating of a wide variety of substrates and the minimization of substrate to applicator distance. A distance of 2-3 cm between the microwave window and substrate has been indicated as desirable.

These requirements dictate a motion of the substrate parallel to the applicator. In the case of the discrete parts coater, the use of a rectangular chamber to maintain the applicator to substrate distance at a minimum, appears the most reasonable.

The continuous product coating system does not readily avail itself to multiple passes in front of each applicator, as can be achieved with the discrete parts coater.

Wire could possible be processed in a chamber configured for discrete parts, however, the fixturing would become extremely complex.

2.2.2. Microwave Windows

The size and shape of the windows place significant penalties on the design of the vessel shell. Stresses induced on the windows as a result of both thermal and vacuum loads must be minimized. This dictates the use of an extremely rigid shell together with some degree of compliance at the window interface, or alternatively, a totally compliant shell/interface design. In addition, active control of both shell and window temperatures would be indicated to minimize or eliminate thermally induced stresses.

An internally mounted liner should be used to minimize radiant energy to the vessel wall both from the IR heating sources and the substrates themselves.

2.2.3. Contamination

A liner for the chamber is desirable to prevent any build up of polymer on the walls of the chamber. This liner should be readily removable for cleaning to prevent degradation of pump-down performance of the system which can arise at low levels of vacuum when significant outgassing is present.

2.3. Pumping System

Trapping of both the mechanical and the diffusion pump ( if incorporated ) is recommended to prevent process contamination as a result of the oil backstreaming from the pumps. In addition, this trapping would appear necessary to prevent contamination of the pumps from the process itself.

2.4. Fixturing and Mechanisms

It is indicated that a low friction coefficient is probably required for guiding of continuous substrates. This requirements would indicate the use of dry film lubricant with substrate temperatures of up to 600°C. Teflon is only suitable for temperatures up to 290°C on continuous operation.

Continuous operation of fixturing drive mechanisms indicate the use of externally mounted motors to allow for cooling requirements. Conduction of heat from the internal fixturing must be limited to protect the chamber drive mechanism. penetrations, therby indicating the use of water cooled penetrations.

Since the plasma coats on optically, a 180° rotation of all parts will be required to assure uniformity of coating.

## 3. CONCEPTUAL DESIGN CONFIGURATION - DISCRETE PART COATING SYSTEM

3.1. Chamber Layout

The overall layout of the conceptual design is briefly described below together with the major components of the system.

3.2. Vacuum Chamber

The vacuum chamber will be rectangular in cross section, approximately 54" high x 30" deep x 60" long, with a full opening door at one end.

It will be fabricated from mild steel plate and suitably reinforced to minimize deflection under vacuum. The interior will be sand-blasted to minimize outgassing.

The exterior of the vessel will be traced with water cooling pipes to minimize shell deflection due to heating from radiation within the chamber.

Eight (8) quartz windows 1m in length x 15cm width will be recessed into the chamber to maintain the required 2-3cm distance between the substrate and also to allow the mounting of the IR heating element on the wall of the chamber. Three (3) windows will be located on each side of the chamber and one (1) on the top and bottom. Sixteen (16) viewports will be provided, one (1) at each end of the microwave windows. All windows will be maintained at a uniform temperature by forced air cooling.

A rotary feedthrough will be provided in the rear of the chamber for the parts rack drive.

Floor mounted rails will be provided for guiding of the parts rack within the chamber.

The full opening door will provide access to the chamber for loading of the parts rack. Loading and unloading of the rack with discrete parts will be undertaken with the rack removed from the chamber.

The chamber will be fitted with a stainless steel liner to minimize contamination of the chamber and radiation to the chamber walls. This liner will be fully removable for cleaning.

3.3. Pumping System

3.3.1. Roughing System

The roughing system will be based on a two stage compound pump with a displacement of between 50-100 CFM. Pump down time to $10^{-3}$ torr is estimated at 15-30 minutes with an ultimate pressure capability of $5 \times 10^{-4}$ torr or better.

The system will include one (1) three inch air operated gate valve and one (1) manually operated throttling valve for regulation of system pressure during processing. The pumping system and processing chamber will both be protected by a refrigerated optically dense chevrom baffle.

3.3.2. Diffusion Pump System

The sizing of the diffusion pumping system is dependent upon the mode under which the system will be operated, ie: is it used to evacuate the chamber before backfilling with monomer or also during process operation. It has been assumed that operation will be during processing. As such, the sizing of the pumping system is based on HVSI's experience with metallizing chambers.

The system will be comprised of one HS16, 4 stage fractionating oil diffusion pump with a speed of 10,000 l/s.

The system will be comprised of one (1) 16" pump, one (1) 16" poppet valve incorporating optically dense chevron baffle, one (1) 5.6 CFM holding pump and one (1) 1" foreline valve.

3.4. Discrete Parts Rack

The parts rack will be trolley mounted for ready installation and removal from the chamber for parts loading and unloading. The rack will be electrically isolated from the chamber to allow a ground bias voltage to be applied.

The parts rack carousel will be driven by the external drive mounted in the chamber wall. This drive will rotate the carousel such that each part will pass parallel to all windows with all sides of the parts being exposed as a result of the rotating motion.

3.5. Controls

All controls will be mounted in a free standing panel enclosure. This panel will include all controls for both vacuum and process control. All components will be interlocked and wired for fail-safe operation.

The parts rack will be provided with full variable speed control.

Chamber pressure will be measured by a capacitance type vacuum gauge and displayed at the control panel.

3.6. Back Filling System

Monomer will be introduced into the chamber by an eight sector distribution system, each sector controlled by a variable aperture manually operated valve. Monomer will be distributed, at the end of each window, downstream of this valve. Flow/pressure regulation of the monomer will be provided as required.

Limited

2755 DE MINIAC, ST-LAURENT, QUE. H4S 1E5 • TELEPHONE: (514) 332-1025 • TELEX: 05-825887

March 24, 1982

M. Georges Archambault
Commercial Analyst
Industrial Innovation Centre
P.O. Box 6079
Stn.A
Montreal, P.Q. H3C 3A7

Dear Mr. Archambault:

We thank you for sending us your interesting and well written description of the coating unit you wish to have built.

Since an accurate price quotation and a proper proposal will involve extensive engineering on our part, we have given you herein an approximate price based on our experience in the construction of similar type vacuum systems:

| | | |
|---|---|---|
| 1. | Engineering to generate complete specifications | $10,000 |
| 2. | Engineering to generate manufacturing drawings of chamber and both types of substrate holders as per your indicated requirements ... | $25,000 |
| 3. | Construction of stainless steel Vacuum Chamber (does not include supply of quartz windows - only the mounts for them) includes water cooling | $35,000 |
| 4. | Heating system, using quartz infrared lamps with individual controls for each ... | $20,000 |
| 5. | Backfilling system for automatic operation including capacitance manometer ... | $20,000 |
| 6. | If a manual system is used - which does not appear to us to be very practical - price would be about .. | $ 2,500 |
| 7. | Vacuum system based on roots blower/mech.pump including valving and throttle possibility .. | $15,000 |

-/2

8. Alternate for diffusion pumped system, automatic with controls .. $28,000

9. Control console to house all system controls fully wired ... $20,000

10. Substrate holder for discrete parts with two axis of rotation ... $12,000

11. Substrate holder for continuous substrates .. $35,000

The pumping system in the case of the roots option is based on the Alcatel M1V350 backed by a 2033 to give a pumping speed of 150 cfm at working pressure (10 Torr to 0.2 Torr). Pump down time to $10^{-3}$ Torr would be of the order of 7 minutes. With the lowest operating pressure envisaged as .2 Torr a diffusion pumped system does not appear to us to be a very viable alternative.

Should you require any further information, please let us know. In the meantime, we hope this "ballpark" indication of prices will be of some assistance to you.

We remain,

Yours truly,
CVE LIMITED

M. Michaels
President

MM/sm